REMARKS/ARGUMENTS

This Reply is timely filed and is in response to an Office Action dated October 14, 2003.

Claims 1, 3-14, 18, 25-47, and 49-59 were pending at the time of the Office Action. Claims 1, 3-14, 18, 38-47, and 49-49 were allowed. Claims 25, 28, 36, and 37 were rejected based on newly cited U.S. Patent No. 6,597,761 B1 to Garms, III ("Garms"). Claims 26, 27, and 29-35 were objected to, but were determined to be allowable if written in independent form to include all limitations of their respective base claim and any intervening claims.

In this Reply, no claims have been amended, canceled, or added.

Now turning to cited art, claims 25, 28, 36, and 37 were rejected under 35 U.S.C. 102(e) based on Garms. According to the Examiner regarding these claims:

> Garms, III shows all of the features of the instant invention including 3D, x-ray, CT imaging of wood and separating the wood into categories based on a resolvable feature of the CT image.

Although Applicants respectfully disagree with some aspects of the above determination, based on Rule 131 Declarations executed by each of the inventors (Marked as exhibits "A") filed herewith, this issue becomes moot because the Declarations remove Garms as a citable reference against the claimed invention. Garms is a 102(e) reference having a filing date as a reference of February 23, 2001. The Invention Disclosure for this case submitted herewith and marked as Exhibit "B" was signed between March 7, 2001 and March 13, 2001. However, notebook records disclosed on page 11 of the Invention Disclosure indicate that the existence of notebook entries describing the claimed invention dated February 12, 2001 and February 14, 2001. These notebook pages are provided herein and marked as Exhibit "C". Thus, the claimed invention was

conceived at least as early as February 12, 2001, thus evidencing conception of the claimed invention before the February 23, 2001 date afforded to Garms as a reference.

Accordingly, based on the Declarations and other supporting evidence provided, Applicants have established prior invention of the claimed subject matter over Garms pursuant to 37 C.F.R. §1.131(b) and MPEP 715.07. Therefore, in light of the evidence submitted herein, Garms, III is no longer a citeable reference against the claimed invention. Accordingly, the rejections of claims 25, 28, 36, and 37 based on Garms should be removed.

Based on this Reply, Applicants have presented claims which are all believed to be in condition for allowance. Therefore, Applicants respectfully request reconsideration and allowance of all pending claims.

Applicants invite the Examiner to call the undersigned if it is believed that a telephonic interview would expedite the prosecution of the application to an allowance.

No fees are believed due with the filing of the above Reply. However, the Commissioner for Patents and Trademarks is hereby authorized to charge any deficiency in any fees due with the filing of this paper or credit any overpayment in any fees paid on the filing, or during prosecution of this application to Deposit Account No. 50-0951.

Respectfully submitted,

Date: 12/22/03

Gregory A. Nelson, Reg. No. 30,577
Neil R. Jetter, Reg. No. 46,803
AKERMAN SENTERFITT
222 Lakeview Avenue; Suite 400
P.O. Box 3188
West Palm Beach, FL 33402-3188
(561) 653-5000

Docket No. 6321-206

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re: Application of WEST et al.

Application No.: 10/029,098 Examiner: Bruce, David V.

Date Filed: December 20, 2001 Group: 2882

For: MEASUREMENT OF WOOD/PLANT CELL OR COMPOSITE MATERIAL ATTRIBUTES WITH COMPUTER ASSISTED TOMOGRAPHY

CERTIFICATE UNDER 37 CFR 1.8(a)
I hereby certify that this correspondence is being deposited with the U.S Postal Service as First Class mail in an envelope addressed to the Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450 on 12/22/03

Reg No 46,803
Neil R. Jetter

DECLARATION UNDER 37 C.F.R. §1.131

Box Non-Fee Amendment
Commissioner for Patents
P O. box 1450
Alexandria, VA 22313-1450

Sir:

I, Darrell C. West, declare:

1. I am a named inventor of the subject matter claimed in the above-captioned application.

2. I have read the Office Action mailed October 14, 2003, and the references cited therein.

3. I have been employed by UT-Battelle, LLC, and by their predecessors in interest, who manages the Oak Ridge National Laboratory since before February 2001. Currently, I am retired from UT-Battelle, LLC.

{WP158268;1}

EXHIBIT "A"

4. I was one of the inventors which conceived of the above-entitled invention in the United States prior to the earliest effective filing date of February 23, 2001 that I have been advised may be afforded to U.S. Pat. No. 6,597,761 B1 to Garms, III.

5. Before February 23, 2001, I, along with my co-inventors, conceived of the claimed subject matter. An Invention Disclosure which describes the claimed invention was submitted to the management at the Oak Ridge National Laboratory and dated between March 7, 2001 and March 13, 2001. The Invention Disclosure is attached hereto and marked as Exhibit "B".

Declarant further states that all statements made herein are of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under §1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Date: 11 Dec 03

Darrell C. West

INVENTION DISCLOSURE
FROM
UT-BATTELLE, LLC

DOE CASE NO.: S- 96,692 **DISCLOSURE NO.: 0934**

SUBMITTED BY: Darrell C. West, Michael J. Paulus, Gerald A. Tuskan and Rupert Wimmer*

TITLE: Measurement of Wood/Plant Cell or Composite Material Attributes with Computer Assisted Tomography

BRIEF DESCRIPTION OF THE INVENTION: The subject invention disclosed herein is a method for measuring cell dimensions, such as cell length, cell diameter and cell wall thickness, of wood and plant cells or other composite material using computer assisted tomography. The existing ORNL rotating-state Micro CT imaging system has been modified and improved by modifying the x-ray tube focal spot size and the system geometry. The system and method of the subject invention are also used to obtain physical measures from reconstituted wood products such as oriented strand board, medium density fiber board and exuded wood products. The measured parameters relate to product quality and product performance. The method and system of the subject invention can be used in production settings to provide real-time quality information on wood and fiber-resin composite products. As such, it can be used in solid timber production facilities, reconstituted wood product facilities, and other fiber-resin production facilities.

N n-enabling title and abstract of the invention: same

DESCRIPTION OF THE INVENTION:
A description of the subject invention, related art, pertinent facts are set forth in the appended Report of Possible Subject Invention.
This invention is related to the following earlier disclosures:

1. ERID 0429 (S-88,699), patent application pending
2. ERID 0521 (S-90,811), patent application pending

POTENTIAL RIGHTS ISSUES:
There does not appear to be any third party involvement in the invention.
The invention does not appear to be subject to an "exceptional circumstance" as defined by the Prime Contract between UT-Battelle and the DOE.

*Visiting scientist on leave from Austrian Agricultural University; Not subject to 35 USC 212 nor 35 USC 202; assigned rights to ORNL

REMARKS:
It appears that: sufficient information is available to form the basis for a patent application; the invention appears to be distinct from known prior art; there is no potential U.S. statutory bar nor potential foreign bar.

Patent Agent: SLS

EXHIBIT
tabbles
"B"

OAK RIDGE NATIONAL LABORATC.Y
MANAGED BY UT-BATTELLE, LLC
FOR THE U.S. DEPARTMENT OF ENERGY

DEC 29 2003
PATENT & TRADEMARK OFFICE

REPORT OF POSSIBLE SUBJECT INVENTION

ORNL-40 *Electronically fillable in WORD 97 or newer* (04/01/2000)

Intelle..tual Pr perty Secti n Use Only
Disclosure No. 0934
DOE S- 96,692

INSTRUCTIONS: Place pointer over highlighted text to reveal instructions here and throughout this document.

PART I - DESCRIPTION OF THE INVENTION

1. SUBMITTER(s): (First/initial/last)

Darrell C. West, Michael J. Paulus, Gerald A. Tuskan, Rupert Wimmer

2. TITLE: (10 words maximum)

Measurement of Wood/Plant Cell or Composite Material Attributes with Computer Assisted Tomography

3. BRIEF DESCRIPTION OF THE INVENTION:

Computer Assisted Tomography (CT) scanning techniques allow direct measurements of wood cell-wall thickness, cell diameter, and cell-vacuole diameter. The system described here consists of a fixed X-ray source, an X-ray detector, and a rotating sample stage. The sample is subjected to a cone beam of X-rays which serves to magnify the image projected into an area detector. The digital image of X-ray attenuation can then be analyzed in either a two- or three-dimensional space. Since the degree of attenuation is a function of material density, quantification is possible for the solid material of the cell wall and the air space (vacuole) within each cell. The digit output and reconstructed images from this approach allows measurements of wood-cell attributes (see Fig. 1).

4. BACKGROUND: (Problem your invention solves)

In pine and hardwood tree species, which are frequently used for pulp, paper and forest products, plant cells form rapid cell walls surrounding an empty vacuole, which can vary in diameter from 10 to 50 um. Within an annual growth cycle, large-diameter, thin-walled cells are produced at the beginning of the growing season, while smaller-diameter, thicker-walled cells are produced near the end of the growing season, thus producing "annual rings." In addition to variation within a given year's growth, wood cell anatomy varies from year to year. The wood formed during the earlier years of growth and near the crown of a tree is called "juvenile" wood and typically has lower density and shorter, thinner-walled fibers than mature wood. Because final paper and/or lumber quality is determined by cell wall attributes, improving wood quality is an important endeavor.

Cell-length and cell-wall-thickness measurements are currently made with standard visual microscopic techniques. However, sample preparation during traditional cell-wall-thickness studies requires several meticulous laboratory steps, including softening and maceration of the wood and microscope slide preparation. Such preparations inadvertently affect the obtained measures. In addition to being cumbersome, cell-length data obtained by the traditional method contain errors because they include measurements of truncated cells produced by the preparation process. Furthermore, large sample-preparation and data-analysis time requirements limit the usefulness of the traditional cell-size-determination procedure in genetic selection studies in which hundreds of samples need to be processed as quickly as possible. The methodology proposed here eliminates the physical, chemical, and visual steps in the laboratory, thus accelerating and simplifying the data-acquisition process and cell attribute determinations.

5. DETAILED DESCRIPTION OF THE INVENTION: (How to make and use, method steps, best mode, drawings of all embodiments)

METHODOLOGY

The resolution and field of view of an X-ray CT system are determined primarily by the X-ray tube focal spot size, the spatial resolution of the X-ray source, and the system geometry. A generic representation of these parameters is presented in Figure 2. As previously configured, the ORNL imaging system was optimized for whole-body mouse scans with a reconstructed image resolution of approximately 100 microns full width, at half maximum (FWHM) and a minimum detectable feature size of about 50 microns.

Image resolution in radiographic systems is frequently defined in terms of the "modulation transfer function" (MTF), which is essentially the frequency (Fourier) domain representation of the spatial resolution. An advantage of MTF analysis is that multiple contributors to the overall spatial resolution may be analyzed independently; the overall resolution is then the frequency-domain product of the individual components.

Results from this reconfigured prototype indicated that a 12-micron resolution, through the use of an X-ray source with a smaller focal spot size and by adjustment of the geometry to ensure that the X-ray focal spot size is the dominant component of the MTF, is achievable. In this high-resolution configuration, the field of view has been reduced to approximately 2.5 mm, but the resolution and field of view is suited for direct measurement of wood cell diameter, cell-wall thickness, and vacuole width. The reconstructed image is approximately 12 um FWHM.

Because cell lumin diameter is greater than the image resolution, this cell dimension is measured directly from the image. Cell-wall thickness is considerably less than the image resolution, thus the average cell-wall thickness is determined by counting the number of cells per unit area, measuring the mean image density, and employing a priori knowledge of the radio-density of the cell wall.

The following is a step-wise progression of procedures used for measuring cell-wall diameter, cell-wall thickness, and vacuole diameter using X-ray Micro-CT:

1. Micro CT images are acquired using a rotating-state micro CT system with resolution of ~10 microns. The system uses a 1024 x 1024 element detector with a field of view of 5.5 mm.

2. Reconstruct a 2-dimensional 1024 x 1024 pixel image slice. Each pixel in the image is 5.4 x 5.4 microns.

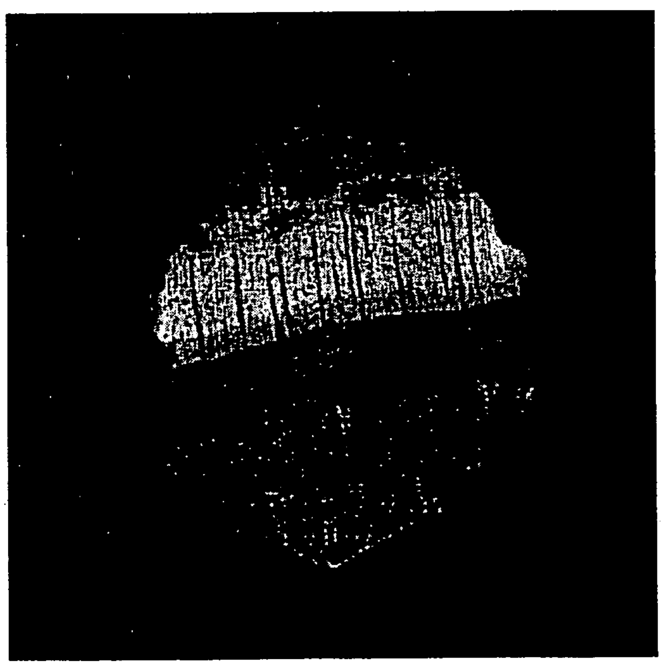

Figure 1. Representative micro CT reconstructed image.

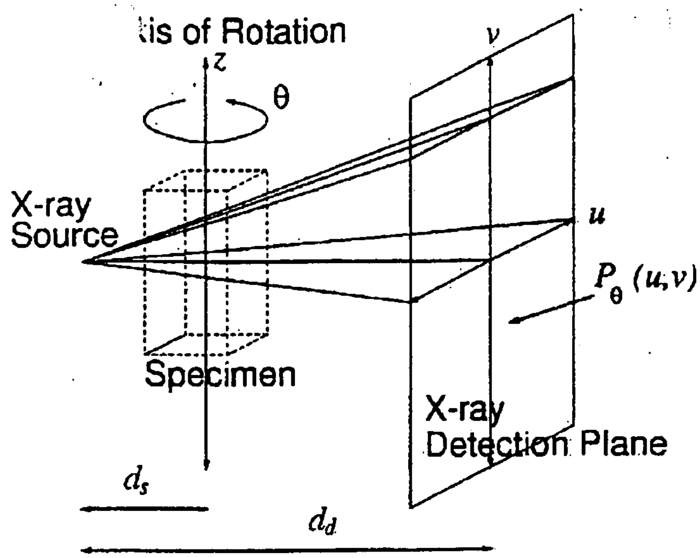

Figure 2. Conceptual representation of the generic configuration of x-ray source, focal spot, and system geometry as it affect spatial resolution.

3. Determine the number of cells per unit length for ~20 radial cell rows (Fig. 3). Determine mean cell size in this dimension.

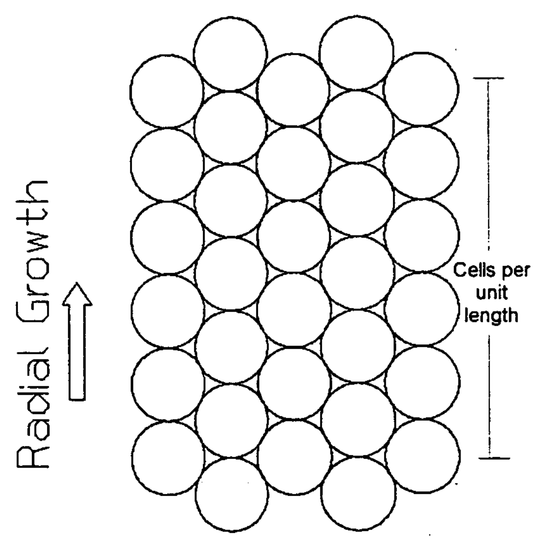

Figure 3. Radial orientation of cell size measurement.

4. Determine the number of tangential rows per unit length (Fig. 4). Determine mean cell size in this dimension.

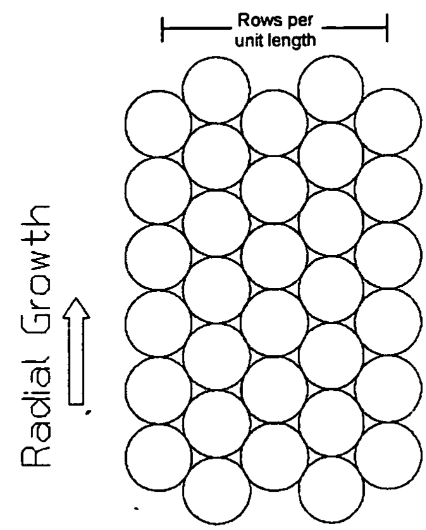

Figure 4. Tangential orientation of cell size measurement.

5. Model the cell as a hexagon with an effective size (flat-to-flat) equal to the average of the radial and tangential cell sizes and with a circular vacuole (Fig. 5).

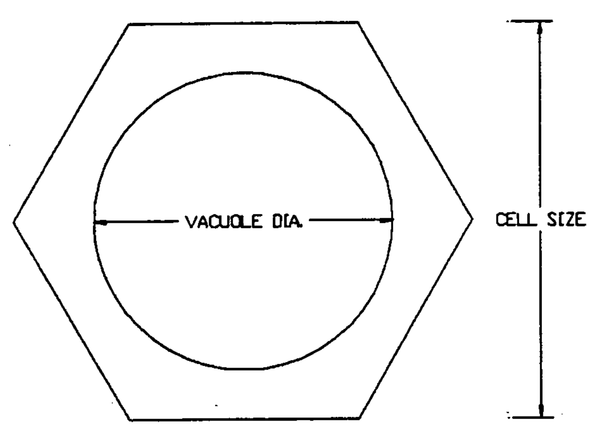

Figure 5. Assumed generic cell geometry.

6. Assume the average radio-density (D_{avg}) may be expressed as:

$$D_{avg} = (A_v D_v + A_c D_c)/(A_v + A_c),$$

Where, A_v is the average vacuole area, D_v is the known radio-density of air, A_c is the average per-cell area of the cellulose cell walls, and D_c is the known radio-density of cellulose. Solve for the fractional areas of the vacuoles and cellulose.

7. Given the known cell size (Step 4) and known fractional areas (Step 6) calculate the vacuole diameter.

8. Calculate the cell wall thickness as the difference between the cell size and the vacuole diameter.

APPARATUS

An apparatus is claimed that will automatically perform all or some of the following functions to analyze wood samples.

1. Trim a raw sample to a size that fits within the field of view of the x-ray computed tomography system or other three-dimensional imaging system.

2. Acquire 3-dimensional image data using x-ray CT or some other imaging method.

3. Determine the average cell size by measuring the mean period (in two dimensions) of the cellular structure.

4. Determine the average cell wall thickness by measuring the mean density of the sample, calculating the ratio of the cell wall material volume to the lumen material, and fitting the ratio to the measured cell size.

5. Automatically determine the average cell length by either

   a. searching the entire image volume for cell ends and determining the number of cell ends per unit volume.

   b. searching one or more 2D image slices for cell ends and extrapolating to estimate the number of cell ends per unit volume.

IMPROVEMENTS

The current resolution is limited by the geometric relationship between the size of the detector array and the size of the X-ray source. Our prototype produces a functional resolution of ca. 12 um. It is technically feasible to achieve a resolution near 1-2 um. At this resolution estimates of cell length are obtainable. In addition, computation time associated with image could be reduced through two modifications to the current prototype. First, the response time of the detector array could be enhanced, shortening the time required to capture the X-ray density data. Second, the computer operating platform could be shifted from a PC base to a UNIX platform on a workstation or to a parallel computer platform.

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6. RELATED TECHNOLOGY: (List all relevant publications, patents, etc. of yours and others, and submit a copy of each with this form.)

o ORNL

Micro CT of small animals (see attached papers)
Micro CT for wood ring analysis, Applied Biotechnology and Biochemistry (see attached papers)

o Elsewhere

X-ray computed tomography is a mature field in the medical community and has also been used to analyze the micro structure of soil, biological and other samples.

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7. UNIQUE FEATURES: (List all features that distinguish the invention over the technology listed in Item 6.)

This is the first time that X-ray CT scan has achieved the above configuration. This is also the first, as a result of the configuration, that direct, non-distributed measures of plant cell wall dimensions are obtainable.

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8. POSSIBLE ALTERNATIVE VERSIONS:

Alternate applications:

1. Determine the uniformity of wood chip orientation in composite materials by performing 2D and 3D Fourier analysis of the image volume.
2. Determine the volumetrically varying orientation of wood chips by performing 2D and 3D Fourier analysis of the image volume.
3. Determine the volumetrically varying wood-to-resin ratio in composite materials by measuring the x-ray attenuation coefficients or other related parameter in composite material samples.
4. Evaluate the defect density in wood and composite material samples through image analysis of the x-ray CT or other image data set.
5. Determine the void density in wood or composite material samples through image analysis of the x-ray CT or other image data set.
6. Determine the volume of moisture uptake in wood or composite material samples through image analysis of the x-ray CT or other image data set.
7. Extend all claims to include any fiber-resin composite materials.

---

9. PROBABLE USES: (Anticipated U.S. Government, Industry, foreign uses of the invention)

We have already described the Micro CT scan's possible use in measuring plant cell attributes such as cell diameter, cell lumin diamtere, cell wall thickness and cell length. This same instrument could be used to obtain physical measures from reconstituted wood products such as oriented strand board, medium density fiber board and exuded wood products. Our preliminary data indicates that measures of fiber orientation, fiber dimensions and fiber to air space measures in these products are feasible. These measured parameters related to product quality and product performance. Instruments could be used in a wide array of research settings -- government and industry wood product laboratories and academic laboratories addressing woody plant structure and function. Furthermore, we could envision the invention being used in production settings to provide real-time quality information on wood and fiber-resin composite products. As such, it could be used in solid timber production facilities, reconstituted wood product facilities, and other fiber-resin production facilities.

PART II - FACTS RELATING TO THE INVENTION

10. REDUCTION TO PRACTICE : Select one of the following responses:

☐ Invention is purely conceptual and needs experimentation to validate the concept.

☐ Invention is conceptual, but does not need experimentation to validate the concept.

☐ Proof-of-principle experiment has been performed to validate the concept.

☒ Invention has been demonstrated on a [☐ laboratory; ☒ prototype; ☐ production] scale.

☐ Other (Explain):

11. SOURCE(S) OF FUNDS: (Funding under which the invention arose)

☐ DOE B&R Code:

☐ 100% funds-in from third party identified below

☐ LDRD

☒ Seed Money

☐ Other:

Identify respective Program Manager: Terry Sjoreen

12. THIRD PARTY: Is a third party involved in the invention? ☐ YES ☒ NO

If yes, provide the following information:

Note: A submitter who is not a UT-Battelle employee is a third party.

☐ CRADA

☐ Subcontract

☐ Interagency Agreement

☐ Work For Others

☐ No written agreement

☐ Other:

Name of third party:

Contract or Agreement No. Effective dates:

Explain any special circumstances:

13. SUBMITTERS: Each submitter must provide all the following information and original signature.

A. Full Name Darrell C. West SS#: 414-74-4623 Citizenship: USA

Residence Address: 2150 Phillips Road, Lenoir City, TN 37771 Telephone: 865-986-6470

Current Employer: ☐ *UT-Battelle* ☒ Other: Retired UT-Battelle

Employee No.: Work Address: Telephone: : - -

DIVISION No.: 42 Name: Environemtnal Sciences Manager: S. G. Hildebrand Supervisor: R. L.Graham

My specific contribution to the concept of the invention is: Project coordinator and initial conceptual development

Recorded in Notebook # Page(s) Date of Entry* Witnessed by:

Employer on *Date of Entry: ☐ *UT-Battelle* ☐ Other:

DIVISION No.: Name: Manager: Supervisor:

If Other, explain relationship to UT-Battelle and provide a copy of agreement, subcontract, or other documentation:

I have read and understood the contents of this document: Signature: NOT AVAILABLE FOR SIGNATURE Date: ________

B. Full Name Michael J. Paulus SS#: 410-13-7816 Citizenship: USA

Residence Address: 1516 Moorgate Drive, Knoxville, TN 37922 Telephone: 865- -

Current Employer: ☒ *UT-Battelle* ☐ Other:

Employee No.: 36220 Work Address: MS-6006 Telephone: : 865-241-4802

DIVISION No.: 9 Name: Instrumentation and Controls Manager: W. L. Bryan Supervisor: W.L. Bryan

My specific contribution to the concept of the invention is: Expertise in CT x-ray densitometry

Recorded in Notebook # A-107984-G Page(s) 40-45 Date of Entry* 2/12/2001 Witnessed by: M.L. Simpson and R.L Graham

Employer on *Date of Entry: ☒ *UT-Battelle* ☐ Other:

DIVISION No.: Name: Manager: Supervisor:

If Other, explain relationship to UT-Battelle and provide a copy of agreement, subcontract, or other documentation:

I have read and understood the contents of this document: Signature: NOT AVAILABLE FOR SIGNATURE Date: ________

C. Full Name Gerald A. Tuskan SS#: 526-23-6899 Citizenship: USA

Residence Address: 120 Newridge Road, Oak Ridge., TN Telephone: 865-481-8346

Current Employer: ☒ *UT-Battelle* ☐ Other:

Employee No.: 30576 Work Address: MS-6422 Telephone: : 865-576-8141

DIVISION No.: 42 Name: Environemntal Sciences Manager: S. G. Hildebrand Supervisor: R. Graham

My specific contribution to the concept of the invention is: Initial conceptual contributions and biological applications.

Recorded in Notebook # Page(s) Date of Entry* Witnessed by:

Employer on *Date of Entry: ☐ *UT-Battelle* ☐ Other:

DIVISION No.: Name: Manager: Supervisor:

If Other, explain relationship to UT-Battelle and provide a copy of agreement, subcontract, or other documentation:

I have read and understood the contents of this document: Signature: Gerald A. Tuskan Date: 3/8/01

D. Full Name Rupert Wimmer SS#: 410-73-4347 Citizenship: Austria

Residence Address: Telephone: - -

Current Employer: ☐ *UT-Battelle* ☒ Other: See Attached Sheet

Employee No.: Work Address: See Attached Sheet Telephone: : - -

DIVISION No.: 42 Name: Environmental Sciences Manager: S. G. Hildebrand Supervisor: S. B. McLaughlin

My specific contribution to the concept of the invention is: Fourier Analysis of density data for oriented strand board.

Recorded in Notebook # Page(s) Date of Entry* Witnessed by:

Employer on *Date of Entry: ☐ *UT-Battelle* ☐ Other:

DIVISION No.: Name: Manager: Supervisor:

If Other, explain relationship to UT-Battelle and provide a copy of agreement, subcontract, or other documentation:

I have read and understood the contents of this document: Signature: NOT AVAILABLE FOR SIGNATURE Date: ________

E Full Name SS#: - - Citizenship:

Residence Address: Telephone: - -

Current Employer: ☐ *UT-Battelle* ☐ Other:

Employee No.: Work Address: Telephone: : - -

DIVISION No.: *Name:* *Manager:* *Supervisor:*

My specific contribution to the concept of the invention is:

Recorded in Notebook # Page(s) Date of Entry* Witnessed by:

Employer on *Date of Entry: ☐ *UT-Battelle* ☐ Other:

DIVISION No.: *Name:* *Manager:* *Supervisor:*

If Other, explain relationship to UT-Battelle and provide a copy of agreement, subcontract, or other documentation:

I have read and understood the contents of this document: Signature: ______________________________ Date: _________

F. Full Name SS#: - - Citizenship:

Residence Address: Telephone: - -

Current Employer: ☐ *UT-Battelle* ☐ Other:

Employee No.: Work Address: Telephone: : - -

DIVISION No.: *Name:* *Manager:* *Supervisor:*

My specific contribution to the concept of the invention is:

Recorded in Notebook # Page(s) Date of Entry* Witnessed by:

Employer on *Date of Entry: ☐ *UT-Battelle* ☐ Other:

DIVISION No.: *Name:* *Manager:* *Supervisor:*

If Other, explain relationship to UT-Battelle and provide a copy of agreement, subcontract, or other documentation:

I have read and understood the contents of this document: Signature: ______________________________ Date: _________

---

14. NOTEBOOK RECORDS : All items <u>must</u> be accurately completed. An inventor <u>cannot</u> be a witness.

EVENT	DATE	NOTEBOOK NO.	PAGES	TWO NOTEBOOK WITNESSES	WITNESS DATES
Original Concept	2/12/2001	A-107984-G	40-45	1. Michael L. Simpson	2/14/2001
				2. Robin L. Graham	2/14/2001
First Sketch or Drawing	2/12/2001	A-107984-G	40-45	1. Michael L. Simpson	2/14/2001
				2. Robin L. Graham	2/14/2001
First Written Description	2/12/2001	A-107984-G	40-45	1. Michael Simpson	2/14/2001
				2. Robin L. Graham	2/14/2001
First Model or Test Unit	2/12/2001	A-107984-G	40-45	1. Michael Simpson	2/14/2001
				2. Robin L. Graham	2/14/2001
First Test of Invention	2/12/2001	A-107984-G	40-45	1. Michael L. Simpson	2/14/2001
				2. Robin L. Graham	2/14/2001

List any other permanent records of the invention:

Please submit with this form copies of notebook entries and other records and reports relating to the invention. These documents may be essential in determining inventorship and date of the invention.

15. PUBLICATION STATUS: Has the invention been disclosed to the public or any party outside DOE and UT-Battelle?

☐YES ☒NO

If yes, provide the following information:

Was the disclosure cleared through the Technical Information Office? ☐YES (attach copy of clearance form) ☐NO

Indicate the form(s) of the disclosure: ☐Oral ☐Visuals ☐Abstract ☐Full Article ☐Other

☐Submitted for review, but not yet published

Date of Conference or Publication: Location of Conference: Journal:

Other relevant information

16. ROUTINE USE OF THE INVENTION:

If the inventors have tested any embodiment of the invention, has there been any additional, routine use of the invention?

☐YES ☒NO

If yes indicate date and circumstances of first such use:

PART III - MANAGEMENT REVIEW: (To be completed by submitter's supervisor, division management, or program manager)

17. Invention Achievement: This invention represents a
☐ Pioneer Breakthrough ☒ Major Improvement ☐ Minor Improvement

18. Claims and Enforceability: (check all that apply)

The invention is a:	☒ Method	☒ Product	☒ Machine	☐ Composition of Matter
Is the invention detectable in a product?	☒ Yes	☐ Somewhat	☒ No (can be practiced in secret)	
Scope of the invention is:	☒ Broad	☐ Intermediate	☐ Narrow	
Discovery by another is likely in:	☐ 1 year	☒ 3 years	☐ 5 years	
"Inventing around" the invention would be:	☐ Easy	☒ Moderate	☐ Difficult	

19. Quality of Description:
☐ Description, documentation, data, drawings, etc. are complete.
☒ Description is reasonably complete.
☐ Further information is needed to support a patent application.

20. Potential Use of the Invention:
☐ U.S. Government only ☒ Manufacturer ☒ Consumer
☒ U.S.A. Companies: Forest Products Industry, Teaching and Research
Products: Wood, Paper, and Fiber Products
☒ Foreign Countries: U.S., All Europe, Brazil, South Africa
Companies:

21. Market Value of the Invention:
Estimated total U.S. market: Present: $13M 5 years $700M
Estimated total world market: Present: $25M 5 years $1.25B
Use by others (1-10) + Near-term potential (1-10) + Value to related invention disclosures (1-10) = Total (≤30)

(+ +) = ☐

22. Recommended Disposition:
☒ UT-Battelle should elect and file patent application. ☐ Program or division will finance patent application.
☐ DOE should file patent application. ☐ Do not file a patent application.

23. Reviewer Comments:

Reviewer Name, printed or typed: Robin L. Graham Position: Section Head
Reviewer Signature: Robin Lambert Graham Date: 3-7-01

24. CLASSIFICATION: (To be completed by classification officer, or derivative classifier if not DUSA)
This document is properly classified as:
☐ Confidential ☐ Secret ☐ Restricted Data ☐ Formerly Restricted Data ☐ National Security Information
☒ Unclassified (Contains no classified information) ☐ **DUSA (no signature required)**
Signature: David R Hamrin Date: 3/8/01

25. RECEIPT BY INTELLECTUAL PROPERTY SECTION: *(This form must be complete in order to be accepted.)*
Received by: Shelley L. Spafford Date: 3-13-01

13. D. Full Name: Rupert Wimmer SS#: 410-73-4347 Citizenship: Austria

Current Employer: Institute of Botany, University of Agricultural Science Vienna

Work Address: Gregor Mendelstrasse 33, A-1180, Vienna, Austria

OIPE JC18 DEC 2 9 2003 PATENT & TRADEMARK OFFICE

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re: Application of WEST et al.

Application No.: 10/029,098 Examiner: Bruce, David V.

Date Filed: December 20, 2001 Group: 2882

For: MEASUREMENT OF WOOD/PLANT CELL OR COMPOSITE MATERIAL ATTRIBUTES WITH COMPUTER ASSISTED TOMOGRAPHY

CERTIFICATE UNDER 37 CFR 1.8(a)
I hereby certify that this correspondence is being deposited with the U.S. Postal Service as First Class mail in an envelope addressed to the Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450 on 12/22/03.

______________ Reg. No. 46,803
~~Neil R. Jetter~~

DECLARATION UNDER 37 C.F.R. §1.131

Box Non-Fee Amendment
Commissioner for Patents
P.O. box 1450
Alexandria, VA 22313-1450

Sir:

I, Michael J. Paulus, declare:

1. I am a named inventor of the subject matter claimed in the above-captioned application.

2. I have read the Office Action mailed October 14, 2003, and the references cited therein.

3. I have been employed by UT-Battelle, LLC, and by their predecessors in interest, who manages the Oak Ridge National Laboratory since before February 2001.

4. I was one of the inventors which conceived of the above-entitled invention in the United States prior to the earliest effective filing date of February 23, 2001 that I have been advised may be afforded to U.S. Pat. No. 6,597,761 B1 to Garms, III.

5. Before February 23, 2001, I, along with my co-inventors, conceived of the claimed subject matter. An Invention Disclosure which describes the claimed invention was submitted to the management at the Oak Ridge National Laboratory and dated between March 7, 2001 and March 13, 2001. The Invention Disclosure is attached hereto and marked as Exhibit "B". In addition, pages 40-45 from my laboratory notebook disclosed in the Invention Disclosure dated February 12, 2001 and February 14, 2001 (marked as Exhibit "C") which describes the claimed invention (also attached hereto).

Declarant further states that all statements made herein are of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under §1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Date: 18 DEC 03

Michael J. Paulus

{WP158282;1}

INVENTION DISCLOSURE
FROM
UT-BATTELLE, LLC

O I P E
DEC 1 9 2003
PATENT & TRADEMARK OFFICE

DOE CASE NO.: S- 96,692 **DISCLOSURE NO.: 0934**

SUBMITTED BY: Darrell C. West, Michael J. Paulus, Gerald A. Tuskan and Rupert Wimmer*

TITLE: Measurement of Wood/Plant Cell or Composite Material Attributes with Computer Assisted Tomography

BRIEF DESCRIPTION OF THE INVENTION: The subject invention disclosed herein is a method for measuring cell dimensions, such as cell length, cell diameter and cell wall thickness, of wood and plant cells or other composite material using computer assisted tomography. The existing ORNL rotating-state Micro CT imaging system has been modified and improved by modifying the x-ray tube focal spot size and the system geometry. The system and method of the subject invention are also used to obtain physical measures from reconstituted wood products such as oriented strand board, medium density fiber board and exuded wood products. The measured parameters relate to product quality and product performance. The method and system of the subject invention can be used in production settings to provide real-time quality information on wood and fiber-resin composite products. As such, it can be used in solid timber production facilities, reconstituted wood product facilities, and other fiber-resin production facilities.

Non-enabling title and abstract of the invention: same

DESCRIPTION OF THE INVENTION:
A description of the subject invention, related art, pertinent facts are set forth in the appended Report of Possible Subject Invention.
This invention is related to the following earlier disclosures:

1. ERID 0429 (S-88,699), patent application pending
2. ERID 0521 (S-90,811), patent application pending

POTENTIAL RIGHTS ISSUES:
There does not appear to be any third party involvement in the invention.
The invention does not appear to be subject to an "exceptional circumstance" as defined by the Prime Contract between UT-Battelle and the DOE.

*Visiting scientist on leave from Austrian Agricultural University; Not subject to 35 USC 212 nor 35 USC 202; assigned rights to ORNL

REMARKS:
It appears that: sufficient information is available to form the basis for a patent application; the invention appears to be distinct from known prior art; there is no potential U.S. statutory bar nor potential foreign bar.

Patent Agent: SLS

EXHIBIT
tabbies
"B"

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE, LLC
FOR THE U.S. DEPARTMENT OF ENERGY

DEC 2 9 2003
PATENT & TRADEMARK OFFICE

Intellectual Property Section Use Only
Disclosure No. 0934
DOE S-96,692

REPORT OF POSSIBLE SUBJECT INVENTION

ORNL-40 *Electronically fillable in WORD 97 or newer* (04/01/2000)

INSTRUCTIONS: Place pointer over highlighted text to reveal instructions here and throughout this document.

PART I - DESCRIPTION OF THE INVENTION

1. SUBMITTER(s): (First/initial/last)

Darrell C. West, Michael J. Paulus, Gerald A. Tuskan, Rupert Wimmer

2. TITLE: (10 words maximum)

Measurement of Wood/Plant Cell or Composite Material Attributes with Computer Assisted Tomography

3. BRIEF DESCRIPTION OF THE INVENTION:

Computer Assisted Tomography (CT) scanning techniques allow direct measurements of wood cell-wall thickness, cell diameter, and cell-vacuole diameter. The system described here consists of a fixed X-ray source, an X-ray detector, and a rotating sample stage. The sample is subjected to a cone beam of X-rays which serves to magnify the image projected into an area detector. The digital image of X-ray attenuation can then be analyzed in either a two- or three-dimensional space. Since the degree of attenuation is a function of material density, quantification is possible for the solid material of the cell wall and the air space (vacuole) within each cell. The digit output and reconstructed images from this approach allows measurements of wood-cell attributes (see Fig. 1).

4. BACKGROUND: (Problem your invention solves)

In pine and hardwood tree species, which are frequently used for pulp, paper and forest products, plant cells form rapid cell walls surrounding an empty vacuole, which can vary in diameter from 10 to 50 um. Within an annual growth cycle, large-diameter, thin-walled cells are produced at the beginning of the growing season, while smaller-diameter, thicker-walled cells are produced near the end of the growing season, thus producing "annual rings." In addition to variation within a given year's growth, wood cell anatomy varies from year to year. The wood formed during the earlier years of growth and near the crown of a tree is called "juvenile" wood and typically has lower density and shorter, thinner-walled fibers than mature wood. Because final paper and/or lumber quality is determined by cell wall attributes, improving wood quality is an important endeavor.

Cell-length and cell-wall-thickness measurements are currently made with standard visual microscopic techniques. However, sample preparation during traditional cell-wall-thickness studies requires several meticulous laboratory steps, including softening and maceration of the wood and microscope slide preparation. Such preparations inadvertently affect the obtained measures. In addition to being cumbersome, cell-length data obtained by the traditional method contain errors because they include measurements of truncated cells produced by the preparation process. Furthermore, large sample-preparation and data-analysis time requirements limit the usefulness of the traditional cell-size-determination procedure in genetic selection studies in which hundreds of samples need to be processed as quickly as possible. The methodology proposed here eliminates the physical, chemical, and visual steps in the laboratory, thus accelerating and simplifying the data-acquisition process and cell attribute determinations.

5. DETAILED DESCRIPTION OF THE INVENTION: (How to make and use, method steps, best mode, drawings of all embodiments)

METHODOLOGY

The resolution and field of view of an X-ray CT system are determined primarily by the X-ray tube focal spot size, the spatial resolution of the X-ray source, and the system geometry. A generic representation of these parameters is presented in Figure 2. As previously configured, the ORNL imaging system was optimized for whole-body mouse scans with a reconstructed image resolution of approximately 100 microns full width, at half maximum (FWHM) and a minimum detectable feature size of about 50 microns.

Image resolution in radiographic systems is frequently defined in terms of the "modulation transfer function" (MTF), which is essentially the frequency (Fourier) domain representation of the spatial resolution. An advantage of MTF analysis is that multiple contributors to the overall spatial resolution may be analyzed independently; the overall resolution is then the frequency-domain product of the individual components.

Results from this reconfigured prototype indicated that a 12-micron resolution, through the use of an X-ray source with a smaller focal spot size and by adjustment of the geometry to ensure that the X-ray focal spot size is the dominant component of the MTF, is achievable. In this high-resolution configuration, the field of view has been reduced to approximately 2.5 mm, but the resolution and field of view is suited for direct measurement of wood cell diameter, cell-wall thickness, and vacuole width. The reconstructed image is approximately 12 um FWHM.

Because cell lumin diameter is greater than the image resolution, this cell dimension is measured directly from the image. Cell-wall thickness is considerably less than the image resolution, thus the average cell-wall thickness is determined by counting the number of cells per unit area, measuring the mean image density, and employing a priori knowledge of the radio-density of the cell wall.

The following is a step-wise progression of procedures used for measuring cell-wall diameter, cell-wall thickness, and vacuole diameter using X-ray Micro-CT:

1. Micro CT images are acquired using a rotating-state micro CT system with resolution of ~10 microns. The system uses a 1024 x 1024 element detector with a field of view of 5.5 mm.

2. Reconstruct a 2-dimensional 1024 x 1024 pixel image slice. Each pixel in the image is 5.4 x 5.4 microns.

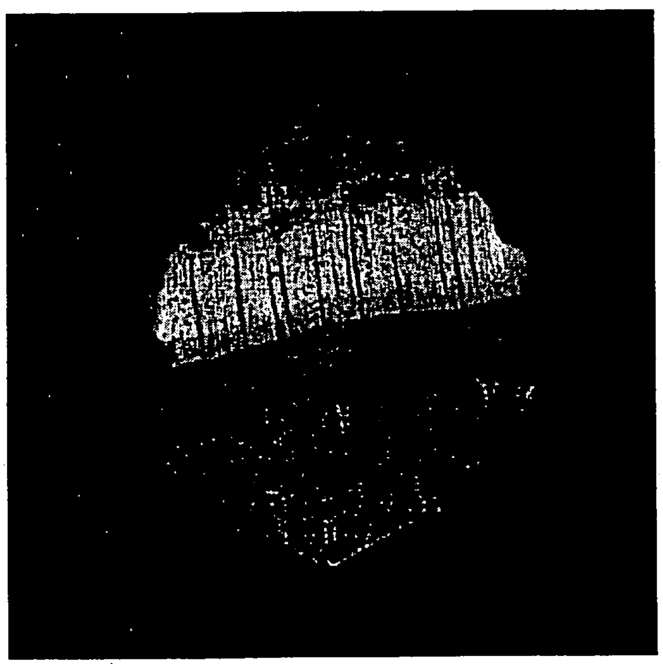

Figure 1. Representative micro CT reconstructed image.

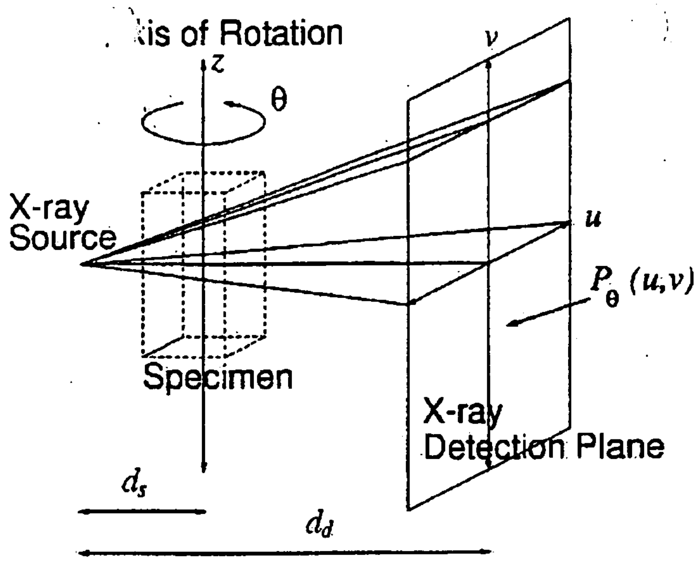

Figure 2. Conceptual representation of the generic configuration of x-ray source, focal spot, and system geometry as it affect spatial resolution.

3. Determine the number of cells per unit length for ~20 radial cell rows (Fig. 3). Determine mean cell size in this dimension.

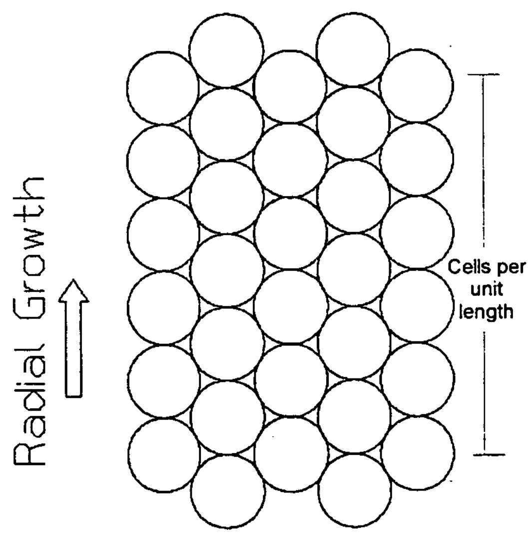

Figure 3. Radial orientation of cell size measurement.

4. Determine the number of tangential rows per unit length (Fig. 4). Determine mean cell size in this dimension.

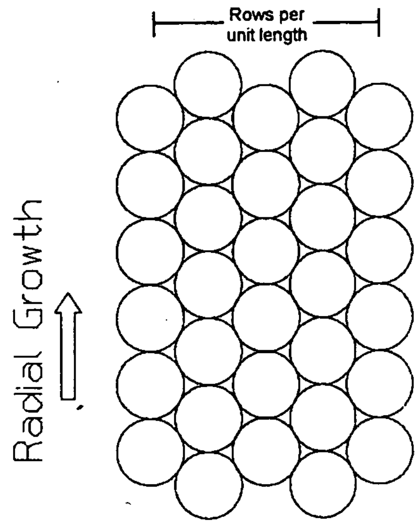

Figure 4. Tangential orientation of cell size measurement.

5. Model the cell as a hexagon with an effective size (flat-to-flat) equal to the average of the radial and tangential cell sizes and with a circular vacuole (Fig. 5).

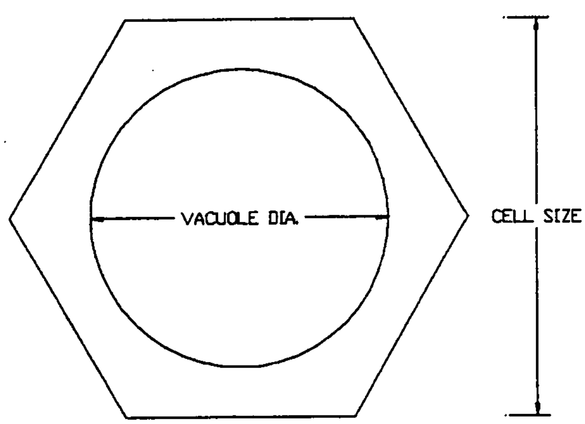

Figure 5. Assumed generic cell geometry.

6. Assume the average radio-density (D_{avg}) may be expressed as:

$$D_{avg} = (A_v D_v + A_c D_c)/(A_v + A_c),$$

Where, A_v is the average vacuole area, D_v is the known radio-density of air, A_c is the average per-cell area of the cellulose cell walls, and D_c is the known radio-density of cellulose. Solve for the fractional areas of the vacuoles and cellulose.

7. Given the known cell size (Step 4) and known fractional areas (Step 6) calculate the vacuole diameter.

8. Calculate the cell wall thickness as the difference between the cell size and the vacuole diameter.

APPARATUS

An apparatus is claimed that will automatically perform all or some of the following functions to analyze wood samples.

1. Trim a raw sample to a size that fits within the field of view of the x-ray computed tomography system or other three-dimensional imaging system.
2. Acquire 3-dimensional image data using x-ray CT or some other imaging method.
3. Determine the average cell size by measuring the mean period (in two dimensions) of the cellular structure.
4. Determine the average cell wall thickness by measuring the mean density of the sample, calculating the ratio of the cell wall material volume to the lumen material, and fitting the ratio to the measured cell size.
5. Automatically determine the average cell length by either
   a. searching the entire image volume for cell ends and determining the number of cell ends per unit volume.
   b. searching one or more 2D image slices for cell ends and extrapolating to estimate the number of cell ends per unit volume.

IMPROVEMENTS

The current resolution is limited by the geometric relationship between the size of the detector array and the size of the X-ray source. Our prototype produces a functional resolution of ca. 12 um. It is technically feasible to achieve a resolution near 1-2 um. At this resolution estimates of cell length are obtainable. In addition, computation time associated with image could be reduced through two modifications to the current prototype. First, the response time of the detector array could be enhanced, shortening the time required to capture the X-ray density data. Second, the computer operating platform could be shifted from a PC base to a UNIX platform on a workstation or to a parallel computer platform.

---

6. RELATED TECHNOLOGY: (List all relevant publications, patents, etc. of yours and others, and submit a copy of each with this form.)

o ORNL

Micro CT of small animals (see attached papers)
Micro CT for wood ring analysis, Applied Biotechnology and Biochemistry (see attached papers)

o Elsewhere

X-ray computed tomography is a mature field in the medical community and has also been used to analyze the micro structure of soil, biological and other samples.

---

7. UNIQUE FEATURES: (List all features that distinguish the invention over the technology listed in Item 6.)

This is the first time that X-ray CT scan has achieved the above configuration. This is also the first, as a result of the configuration, that direct, non-distributed measures of plant cell wall dimensions are obtainable.

---

8. POSSIBLE ALTERNATIVE VERSIONS:

Alternate applications:

1. Determine the uniformity of wood chip orientation in composite materials by performing 2D and 3D Fourier analysis of the image volume.
2. Determine the volumetrically varying orientation of wood chips by performing 2D and 3D Fourier analysis of the image volume.
3. Determine the volumetrically varying wood-to-resin ratio in composite materials by measuring the x-ray attenuation coefficients or other related parameter in composite material samples.
4. Evaluate the defect density in wood and composite material samples through image analysis of the x-ray CT or other image data set.
5. Determine the void density in wood or composite material samples through image analysis of the x-ray CT or other image data set.
6. Determine the volume of moisture uptake in wood or composite material samples through image analysis of the x-ray CT or other image data set.
7. Extend all claims to include any fiber-resin composite materials.

---

9. PROBABLE USES: (Anticipated U.S. Government, Industry, foreign uses of the invention)

We have already described the Micro CT scan's possible use in measuring plant cell attributes such as cell diameter, cell lumin diamtere, cell wall thickness and cell length. This same instrument could be used to obtain physical measures from reconstituted wood products such as oriented strand board, medium density fiber board and exuded wood products. Our preliminary data indicates that measures of fiber orientation, fiber dimensions and fiber to air space measures in these products are feasible. These measured parameters related to product quality and product performance. Instruments could be used in a wide array of research settings -- government and industry wood product laboratories and academic laboratories addressing woody plant structure and function. Furthermore, we could envision the invention being used in production settings to provide real-time quality information on wood and fiber-resin composite products. As such, it could be used in solid timber production facilities, reconstituted wood product facilities, and other fiber-resin production facilities.

PART II - FACTS RELATING TO THE INVENTION

10. REDUCTION TO PRACTICE : Select one of the following responses:

- ☐ Invention is purely conceptual and needs experimentation to validate the concept.
- ☐ Invention is conceptual, but does not need experimentation to validate the concept.
- ☐ Proof-of-principle experiment has been performed to validate the concept.
- ☒ Invention has been demonstrated on a [☐ laboratory; ☒ prototype; ☐ production] scale.
- ☐ Other (Explain):

11. SOURCE(S) OF FUNDS: (Funding under which the invention arose)

- ☐ DOE B&R Code:
- ☐ LDRD
- ☐ Other:
- ☐ 100% funds-in from third party identified below
- ☒ Seed Money

Identify respective Program Manager: Terry Sjoreen

12. THIRD PARTY: Is a third party involved in the invention? ☐ YES ☒ NO

If yes, provide the following information:

Note: A submitter who is not a UT-Battelle employee is a third party.

- ☐ CRADA
- ☐ Subcontract
- ☐ Interagency Agreement
- ☐ Work For Others
- ☐ No written agreement
- ☐ Other:

Name of third party:

Contract or Agreement No. Effective dates:

Explain any special circumstances:

13. SUBMITTERS: Each submitter must provide all the following information and original signature.

A. Full Name Darrell C. West SS#: 414-74-4623 Citizenship: USA

Residence Address: 2150 Phillips Road, Lenoir City, TN 37771 Telephone: 865-986-6470

Current Employer: ☐ *UT-Battelle* ☒ Other: Retired UT-Battelle

Employee No.: Work Address: Telephone: : - -

DIVISION No.: 42 Name: Environemtnal Sciences Manager: S. G. Hildebrand Supervisor: R. L.Graham

My specific contribution to the concept of the invention is: Project coordinator and initial conceptual development

Recorded in Notebook # Page(s) Date of Entry* Witnessed by:

Employer on *Date of Entry: ☐ *UT-Battelle* ☐ Other:

DIVISION No.: Name: Manager: Supervisor:

If Other, explain relationship to UT-Battelle and provide a copy of agreement, subcontract, or other documentation:

I have read and understood the contents of this document: Signature: NOT AVAILABLE FOR SIGNATURE Date: ________

B. Full Name Michael J. Paulus SS#: 410-13-7816 Citizenship: USA

Residence Address: 1516 Moorgate Drive, Knoxville, TN 37922 Telephone: 865- -

Current Employer: ☒ *UT-Battelle* ☐ Other:

Employee No.: 36220 Work Address: MS-6006 Telephone: : 865-241-4802

DIVISION No.: 9 Name: Instrumentation and Controls Manager: W. L. Bryan Supervisor: W.L. Bryan

My specific contribution to the concept of the invention is: Expertise in CT x-ray densitometry

Recorded in Notebook # A-107984-G Page(s) 40-45 Date of Entry* 2/12/2001 Witnessed by: M.L. Simpson and R.L Graham

Employer on *Date of Entry: ☒ *UT-Battelle* ☐ Other:

DIVISION No.: Name: Manager: Supervisor:

If Other, explain relationship to UT-Battelle and provide a copy of agreement, subcontract, or other documentation:

I have read and understood the contents of this document: Signature: NOT AVAILABLE FOR SIGNATURE Date: ________

C. Full Name Gerald A. Tuskan SS#: 526-23-6899 Citizenship: USA

Residence Address: 120 Newridge Road, Oak Ridge., TN Telephone: 865-481-8346

Current Employer: ☒ *UT-Battelle* ☐ Other:

Employee No.: 30576 Work Address: MS-6422 Telephone: : 865-576-8141

DIVISION No.: 42 Name: Environemntal Sciences Manager: S. G. Hildebrand Supervisor: R. Graham

My specific contribution to the concept of the invention is: Initial conceptual contributions and biological applications.

Recorded in Notebook # Page(s) Date of Entry* Witnessed by:

Employer on *Date of Entry: ☐ *UT-Battelle* ☐ Other:

DIVISION No.: Name: Manager: Supervisor:

If Other, explain relationship to UT-Battelle and provide a copy of agreement, subcontract, or other documentation:

I have read and understood the contents of this document: Signature: Gerald A. Tuskan Date: 3/8/01

D. Full Name Rupert Wimmer SS#: 410-73-4347 Citizenship: Austria

Residence Address: Telephone: - -

Current Employer: ☐ *UT-Battelle* ☒ Other: See Attached Sheet

Employee No.: Work Address: See Attached Sheet Telephone: : - -

DIVISION No.: 42 Name: Environmental Sciences Manager: S. G. Hildebrand Supervisor: S. B. McLaughlin

My specific contribution to the concept of the invention is: Fourier Analysis of density data for oriented strand board.

Recorded in Notebook # Page(s) Date of Entry* Witnessed by:

Employer on *Date of Entry: ☐ *UT-Battelle* ☐ Other:

DIVISION No.: Name: Manager: Supervisor:

If Other, explain relationship to UT-Battelle and provide a copy of agreement, subcontract, or other documentation:

I have read and understood the contents of this document: Signature: NOT AVAILABLE FOR SIGNATURE Date: ________

E Full Name SS#: - - Citizenship:

Residence Address: Telephone: - -

Current Employer: ☐ *UT-Battelle* ☐ Other:

Employee No.: Work Address: Telephone: : - -

DIVISION No.: *Name:* *Manager:* *Supervisor:*

My specific contribution to the concept of the invention is:

Recorded in Notebook # Page(s) Date of Entry* Witnessed by:

Employer on *Date of Entry: ☐ *UT-Battelle* ☐ Other:

DIVISION No.: *Name:* *Manager:* *Supervisor:*

If Other, explain relationship to UT-Battelle and provide a copy of agreement, subcontract, or other documentation:

I have read and understood the contents of this document: Signature: ______________________________ Date: _________

F. Full Name SS#: - - Citizenship:

Residence Address: Telephone: - -

Current Employer: ☐ *UT-Battelle* ☐ Other:

Employee No.: Work Address: Telephone: : - -

DIVISION No.: *Name:* *Manager:* *Supervisor:*

My specific contribution to the concept of the invention is:

Recorded in Notebook # Page(s) Date of Entry* Witnessed by:

Employer on *Date of Entry: ☐ *UT-Battelle* ☐ Other:

DIVISION No.: *Name:* *Manager:* *Supervisor:*

If Other, explain relationship to UT-Battelle and provide a copy of agreement, subcontract, or other documentation:

I have read and understood the contents of this document: Signature: ______________________________ Date: _________

14. NOTEBOOK RECORDS : All items must be accurately completed. An inventor cannot be a witness.

EVENT	DATE	NOTEBOOK NO.	PAGES	TWO NOTEBOOK WITNESSES	WITNESS DATES
Original Concept	2/12/2001	A-107984-G	40-45	1. Michael L. Simpson	2/14/2001
				2. Robin L. Graham	2/14/2001
First Sketch or Drawing	2/12/2001	A-107984-G	40-45	1. Michael L. Simpson	2/14/2001
				2. Robin L. Graham	2/14/2001
First Written Description	2/12/2001	A-107984-G	40-45	1. Michael Simpson	2/14/2001
				2. Robin L. Graham	2/14/2001
First Model or Test Unit	2/12/2001	A-107984-G	40-45	1. Michael Simpson	2/14/2001
				2. Robin L. Graham	2/14/2001
First Test of Invention	2/12/2001	A-107984-G	40-45	1. Michael L. Simpson	2/14/2001
				2. Robin L. Graham	2/14/2001

List any other permanent records of the invention:

Please submit with this form copies of notebook entries and other records and reports relating to the invention. These documents may be essential in determining inventorship and date of the invention.

---

15. PUBLICATION STATUS: Has the invention been disclosed to the public or any party outside DOE and UT-Battelle?

☐YES ☒ NO

If yes, provide the following information:

Was the disclosure cleared through the Technical Information Office? ☐YES (attach copy of clearance form) ☐NO

Indicate the form(s) of the disclosure: ☐Oral ☐Visuals ☐Abstract ☐Full Article ☐Other

☐Submitted for review, but not yet published

Date of Conference or Publication: Location of Conference: Journal:

Other relevant information

---

16. ROUTINE USE OF THE INVENTION:

If the inventors have tested any embodiment of the invention, has there been any additional, routine use of the invention?

☐YES ☒NO

If yes indicate date and circumstances of first such use:

PART III - MANAGEMENT REVIEW: (To be completed by submitter's supervisor, division management, or program manager)

17. Invention Achievement: This invention represents a
☐ Pioneer Breakthrough ☒ Major Improvement ☐ Minor Improvement

18. Claims and Enforceability: (check all that apply)

The invention is a:	☒ Method	☒ Product	☒ Machine	☐ Composition of Matter
Is the invention detectable in a product?	☒ Yes	☐ Somewhat	☒ No (can be practiced in secret)	
Scope of the invention is:	☒ Broad	☐ Intermediate	☐ Narrow	
Discovery by another is likely in:	☐ 1 year	☒ 3 years	☐ 5 years	
"Inventing around" the invention would be:	☐ Easy	☒ Moderate	☐ Difficult	

19. Quality of Description:
☐ Description, documentation, data, drawings, etc. are complete.
☒ Description is reasonably complete.
☐ Further information is needed to support a patent application.

20. Potential Use of the Invention:
☐ U.S. Government only ☒ Manufacturer ☒ Consumer
☒ U.S.A. Companies: Forest Products Industry, Teaching and Research
Products: Wood, Paper, and Fiber Products
☒ Foreign Countries: U.S., All Europe, Brazil, South Africa
Companies:

21. Market Value of the Invention:
Estimated total U.S. market: Present: $13M 5 years $700M
Estimated total world market: Present: $25M 5 years $1.25B
Use by others (1-10) + Near-term potential (1-10) + Value to related invention disclosures (1-10) = Total (≤30)

(+ +) = ☐

22. Recommended Disposition:
☒ UT-Battelle should elect and file patent application. ☐ Program or division will finance patent application.
☐ DOE should file patent application. ☐ Do not file a patent application.

23. Reviewer Comments:

Reviewer Name, printed or typed: Robin L. Graham Position: Section Head

Reviewer Signature: Robin Lambert Graham Date: 3-7-01

24. CLASSIFICATION: (To be completed by classification officer, or derivative classifier if not DUSA)
This document is properly classified as:
☐ Confidential ☐ Secret ☐ Restricted Data ☐ Formerly Restricted Data ☐ National Security Information
☒ Unclassified (Contains no classified information) ☐ **DUSA (no signature required)**

Signature: David R Hamrin Date: 3/8/01

25. RECEIPT BY INTELLECTUAL PROPERTY SECTION: *(This form must be complete in order to be accepted.)*

Received by: Shelley L. Spafford Date: 3-13-01

CONFIDENTIAL INFORMATION
This document contains patentable subject matter and is disclosed in confidence by UT-Battelle, LLC under 35 USC § 205.

13. D. Full Name: Rupert Wimmer SS#: 410-73-4347 Citizenship: Austria

Current Employer: Institute of Botany, University of Agricultural Science Vienna

Work Address: Gregor Mendelstrasse 33, A-1180, Vienna, Austria

Subject Micro CT for Wood Anatomy Studies

Date FEB 12 ~~19~~ 2001 Year

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE, LLC
FOR THE U.S. DEPARTMENT OF ENERGY

REPORT OF POSSIBLE SUBJECT INVENTION

ORNL-40 Electronically fillable in WORD 97 or newer (04/01/2000)

Intellectual Property Section Use Only

Disclosure No. ______

DOE S-______

INSTRUCTIONS: Place pointer over highlighted text to reveal instructions here and throughout this document.[JM1]

PART I - DESCRIPTION OF THE INVENTION

1. SUBMITTER(s): [JM2] (First/initial/last)

Darrell C. West, Michael J. Paulus, Gerald A. Tuskan

2. TITLE: [JM3] (10 words maximum)

Measurement of Wood/Plant Cell Attributes with Computer Assisted Tomography

3. BRIEF DESCRIPTION OF THE INVENTION:[JM4]

Computer Assisted Tomography (CT) scanning techniques allow direct measurements of wood cell-wall thickness, cell diameter, and cell-vacuole diameter. The system described here consists of a fixed X-ray source, an X-ray detector, and a rotating sample stage. The sample is subjected to a cone beam of X-rays which serves to magnify the image projected into an area detector. The digital image of X-ray attenuation can then be analyzed in either a two- or three-dimensional space. Since the degree of a attenuation is a function of material density, quantification is possible for the solid material of the cell wall and the air space (vacuole) within each cell. The digit output and reconstructed images from this approach allows measurements of wood-cell attributes (see Fig. 1).

4. BACKGROUND: [JM5] (Problem your invention solves)

In pine and hardwood tree species, which are frequently used for pulp, paper and forest products, plant cells form rapid cell walls surrounding an empty vacuole which can vary in diameter from 10 to 50 um. Within an annual growth cycle, large-diameter, thin-walled cells are produced at the beginning of the growing season, while smaller-diameter, thicker-walled cells are produced near the end of the growing season, thus producing "annual rings." In addition to variation within a given year's growth, wood cell anatomy varies from year to year. The wood formed during the earlier years of growth and near the crown of a tree is called "juvenile" wood and typically has lower density and shorter, thinner-walled fibers than mature wood. Because final paper and/or lumber quality is determined by cell wall attributes, improving wood quality is an important endeavor.

Cell-length and cell-wall-thickness measurements are currently made with standard visual microscopic techniques. However, sample preparation during traditional cell-wall-thickness studies requires several meticulous laboratory steps, including softening and maceration of the wood and microscope slide preparation. Such preparations inadvertently affects the obtained measures. In addition to being cumbersome, cell-length data obtained by the traditional method contain errors because they include measurements of truncated cells produced by the preparation process. Furthermore, large sample-preparation and data-analysis time requirements limit the usefulness of the traditional cell-size-determination procedure in genetic selection studies in which hundreds of samples need to be processed as quickly as possible. The methodology proposed here eliminates the physical, chemical, and visual steps in the laboratory, thus accelerating and simplifying the data-acquisition process and cell attribute determinations.

5. DETAILED DESCRIPTION OF THE INVENTION:[JM6] (How to make and use, method steps, best mode, drawings of all embodiments)

The resolution and field of view of a X-ray CT system are determined primarily by the X-ray tube focal spot size, the spatial resolution of the X-ray source, and the system geometry. A generic representation of these parameters is presented in Figure 2. As previously configured, the ORNL imaging system was optimized for whole-body mouse scans with a reconstructed image resolution of approximately 100 microns full width, at half maximum (FWHM) and a minimum detectable feature size of about 50 microns.

Image resolution in radiographic systems is frequently defined in terms of the "modulation transfer function" (MTF), which is essentially the frequency (Fourier) domain representation of the spatial resolution. An advantage of MTF analysis is that multiple

CONFIDENTIAL INFORMATION
This document contains patentable subject matter and is disclosed in confidence by UT-Battelle, LLC under 35 USC § 205.

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Michael J Paulus FEB 12, 2001

Gerald Tuskan 2/14/01

Robin L Graham 2/14/01

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Bodge 34325

Subject Micro CT For Wood Anatomy Studies

Date FEB 12 2001 ~~19~~
Month Day Year

contributors to the overall spatial resolution may be analyzed independently; the overall resolution is then the frequency-domain product of the individual components.

Results from this reconfigured prototype indicated that a 12-micron resolution, through the use of an X-ray source with a smaller focal spot size and by adjustment of the geometry to ensure that the X-ray focal spot size is the dominant component of the MTF, is achievable. In this high-resolution configuration, the field of view has been reduced to approximately 2.5 mm, but the resolution and field of view is suited for direct measurement of wood cell diameter, cell-wall thickness, and vacuole width. The reconstructed image is approximately 12 um FWHM.

Because cell lumin diameter is greater than the image resolution, this cell dimension is measured directly from the image. Cell-wall thickness is considerably less than the image resolution, thus the average cell-wall thickness is determined by counting the number of cells per unit area, measuring the mean image density, and employing a priori knowledge of the radio-density of the cell wall.

The following is a step-wise progression of procedures used for measuring cell-wall diameter, cell-wall thickness, and vacuole diameter using X-ray Micro-CT:

1. MicroCT images are acquired using a rotating-state microCT system with resolution of ~10 microns. The system uses a 1024 x 1024 element detector with a field of view of 5.5 mm.

2. Reconstruct a 2-dimensional 1024 x 1024 pixel image slice. Each pixel in the image is 5.4 x 5.4 microns.

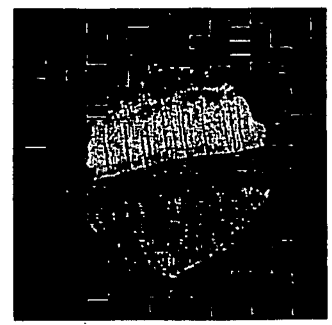

Figure 1. Representative micro CT reconstructed image.

Michael J Paulus FEB 12, 2001

Robin L Graham 2/14/01

Gerald A Tuskan 2/14/01

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Subject Micro CT for Wood Anatomy Studies

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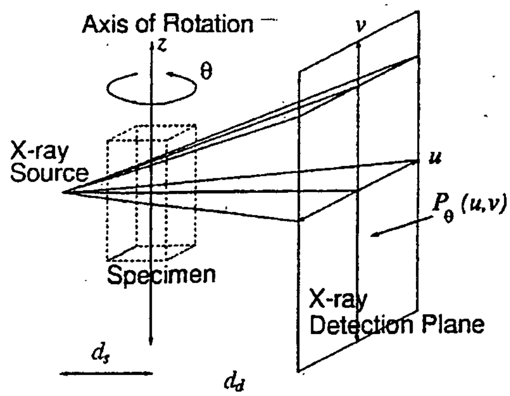

Figure 2. Conceptual representation of the generic configuration of x-ray source, focal spot, and system geometry as it affect spatial resolution.

3. Determine the number of cells per unit length for ~20 radial cell rows (Fig. 3). Determine mean cell size in this dimension.

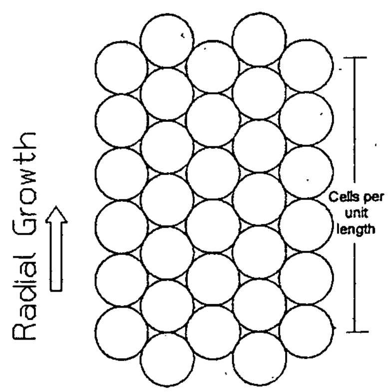

Figure 3. Radial orientation of cell size measurement.

Feb 12, 2001

Robin L. Graham 2-14-01

Gerald A. Tuskan 2/14/01

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Subject Micro CT for Wood Anatomy Studies

Date FEB 12, 2001 ~~19~~
Month Day Year

4. Determine the number of tangential rows per unit length (Fig. 4). Determine mean cell size in this dimension.

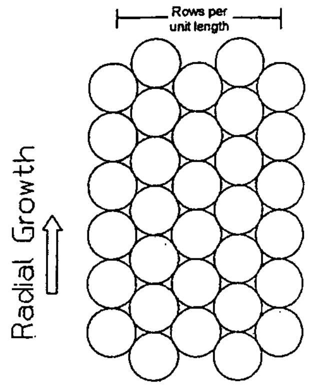

Figure 4. Tangential orientation of cell size measurement.

5. Model the cell as a hexagon with an effective size (flat-to-flat) equal to the average of the radial and tangential cell sizes and with a circular vacuole (Fig. 5).

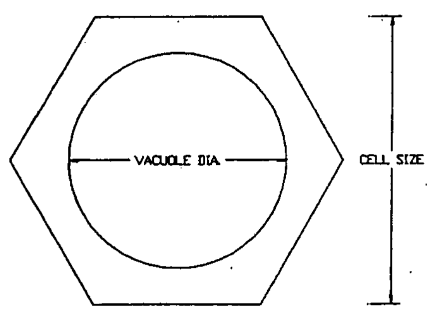

Figure 5. Assumed generic cell geometry.

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6. Assume the average radio-density (D_{avg}) may be expressed as:

$$D_{avg} = (A_v D_v + A_c D_c)/(A_v + A_c),$$

Where, A_v is the average vacuole area, D_v is the known radio-density of air, A_c is the average per-cell area of the cellulose cell walls, and D_c is the known radio-density of cellulose. Solve for the fractional areas of the vacuoles and cellulose.

7. Given the known cell size (Step 4) and known fractional areas (Step 6) calculate the vacuole diameter.

8. Calculate the cell wall thickness as the difference between the cell size and the vacuole diameter.

6. RELATED TECHNOLOGY:[JM7] (List all relevant publications, patents, etc. of yours and others, and submit a copy of each with this form

Mike you will have to complete this section.

7. UNIQUE FEATURES: [JM8] (List all features that distinguish the invention over the technology listed in Item 6.)

This is the first time that X-ray CT scan has achieved the above configuration. This is also the first, as a result of the configuration, that direct, non-distributed measures of plant cell wall dimensions are obtainable.

8. POSSIBLE ALTERNATIVE VERSIONS:[JM9]

The current resolution is limited by the geometric relationship between the size of the detector array and the size of the X-ray source. Our prototype produces a functional resolution of ca. 12 um. It is technically feasible to achieve a resolution near 1-2 um. At this resolution estimates of cell length are obtainable. In addition, computation time associated with image could be reduced through two modifications to the current prototype. First, the response time of the detector array could be enhanced, shortening the time required to capture the X-ray density data. Second, the computer operating platform could be shifted from a PC base to a UNIX platform on a workstation or to a parallel computer platform. This would require some codes to be re-written.

9. PROBABLE USES: [JM10] (Anticipated U.S. Government, Industry, foreign uses of the invention)

We have already described the Micro-CT scans possible use in measuring plant cell attributes such as cell diameter, cell lumin diamtere, cell wall thickness and cell length. This same instrument could be used to obtain physical measures from reconstituted wood products such as oriented strand board, medium density fiber board and exuded wood products. Our preliminary data indicates that measures of fiber orientation, fiber dimensions and fiber to air space measures in these products are feasible. These measured parameters related to product quality and product performance.

Feb 12, 2001

Robert Graham 2/14/01

2/14/01

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Badge 34385

Subject MicroCT for Wood Anatomy Studies

Date FEB 12, 2001 ~~19~~
Month Day Year

Apparatus

An apparatus is claimed that will automatically perform all or some of the following functions to analyze wood samples.

1. Trim a raw sample to a size that fits within the field of view of the x-ray computed tomography system or other three-dimensional imaging system.

2. Acquire 3-dimensional image data using x-ray CT or some other imaging method.

3. Determine the average cell size by measuring the mean period (in two dimensions) of the cellular structure.

4. Determine the average cell wall thickness by measuring the mean density of the sample, calculating the ratio of the cell wall material volume to the lumen material, and fitting the ratio to the measured cell size.

5. Automatically determine the average cell length by either

   a. searching the entire image volume for cell ends and determining the number of cell ends per unit volume.

   b. searching one or more 2D image slices for cell ends and extrapolating to estimate the number of cell ends per unit volume.

Alternate applications:

1. Determine the uniformity of wood chip orientation in composite materials by performing 2D and 3D Fourier analysis of the image volume.

2. Determine the volumetrically varying orientation of wood chips by performing 2D and 3D Fourier analysis of the image volume.

3. Determine the volumetrically varying wood-to-resin ratio in composite materials by measuring the x-ray attenuation coefficients or other related parameter in composite material samples.

4. Evaluate the defect density in wood and composite material samples through image analysis of the x-ray CT or other image data set.

5. Determine the void density in wood or composite material samples through image analysis of the x-ray CT or other image data set.

6. Determine the volume of moisture uptake in wood or composite material samples through image analysis of the x-ray CT or other image data set.

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PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re: Application of WEST et al.

Application No.: 10/029,098 Examiner: Bruce, David V.

Date Filed: December 20, 2001 Group: 2882

For: MEASUREMENT OF WOOD/PLANT CELL OR COMPOSITE MATERIAL ATTRIBUTES WITH COMPUTER ASSISTED TOMOGRAPHY

CERTIFICATE UNDER 37 CFR 1.8(a)
I hereby certify that this correspondence is being deposited with the U.S. Postal Service as First Class mail in an envelope addressed to the Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450 on 12/22/03.

Neil R. Jetter Reg. No. 46,803

DECLARATION UNDER 37 C.F.R. §1.131

Box Non-Fee Amendment
Commissioner for Patents
P.O. box 1450
Alexandria, VA 22313-1450

Sir:

I, Gerald A. Tuskan, declare:

1. I am a named inventor of the subject matter claimed in the above-captioned application.

2. I have read the Office Action mailed October 14, 2003, and the references cited therein.

3. I have been employed by UT-Battelle, LLC, and by their predecessors in interest, who manages the Oak Ridge National Laboratory since before February 2001.

4. I was one of the inventors which conceived of the above-entitled invention in the United States prior to the earliest effective filing date of February 23, 2001 that I have been advised may be afforded to U.S. Pat. No. 6,597,761 B1 to Garms, III.

5. Before February 23, 2001, I, along with my co-inventors, conceived of the claimed subject matter. An Invention Disclosure which describes the claimed invention was submitted to the management at the Oak Ridge National Laboratory and dated between March 7, 2001 and March 13, 2001. The Invention Disclosure is attached hereto and marked as Exhibit "B". In addition, I witnessed and signed pages 40-45 from Dr. Michael J. Paulus' laboratory notebook disclosed in the Invention Disclosure dated February 12, 2001 and February 14, 2001 (marked as Exhibit "C") which describes the claimed invention (also attached hereto).

Declarant further states that all statements made herein are of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under §1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Date: 12/8/2003

Gerald A. Tuskan

{WP158284;1}

INVENTION DISCLOSURE
FROM
UT-BATTELLE, LLC

OIPE DEC 29 2003 PATENT & TRADEMARK OFFICE

DOE CASE NO.: S- 96,692 **DISCLOSURE NO.: 0934**

SUBMITTED BY: Darrell C. West, Michael J. Paulus, Gerald A. Tuskan and Rupert Wimmer*

TITLE: Measurement of Wood/Plant Cell or Composite Material Attributes with Computer Assisted Tomography

BRIEF DESCRIPTION OF THE INVENTION: The subject invention disclosed herein is a method for measuring cell dimensions, such as cell length, cell diameter and cell wall thickness, of wood and plant cells or other composite material using computer assisted tomography. The existing ORNL rotating-state Micro CT imaging system has been modified and improved by modifying the x-ray tube focal spot size and the system geometry. The system and method of the subject invention are also used to obtain physical measures from reconstituted wood products such as oriented strand board, medium density fiber board and exuded wood products. The measured parameters relate to product quality and product performance. The method and system of the subject invention can be used in production settings to provide real-time quality information on wood and fiber-resin composite products. As such, it can be used in solid timber production facilities, reconstituted wood product facilities, and other fiber-resin production facilities.

Non-enabling title and abstract of the invention: same

DESCRIPTION OF THE INVENTION:
A description of the subject invention, related art, pertinent facts are set forth in the appended Report of Possible Subject Invention.
This invention is related to the following earlier disclosures:

1. ERID 0429 (S-88,699), patent application pending
2. ERID 0521 (S-90,811), patent application pending

POTENTIAL RIGHTS ISSUES:
There does not appear to be any third party involvement in the invention.
The invention does not appear to be subject to an "exceptional circumstance" as defined by the Prime Contract between UT-Battelle and the DOE.

*Visiting scientist on leave from Austrian Agricultural University; Not subject to 35 USC 212 nor 35 USC 202; assigned rights to ORNL

REMARKS:
It appears that: sufficient information is available to form the basis for a patent application; the invention appears to be distinct from known prior art; there is no potential U.S. statutory bar nor potential foreign bar.

Patent Agent: SLS

EXHIBIT
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OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE, LLC
FOR THE U.S. DEPARTMENT OF ENERGY

DEC 29 2003
PATENT & TRADEMARK OFFICE

REPORT OF POSSIBLE SUBJECT INVENTION

ORNL-40 *Electronically fillable in WORD 97 or newer* (04/01/2000)

Intellectual Property Section Use Only
Disclosure No. 0934
DOE S-96,692

INSTRUCTIONS: Place pointer over highlighted text to reveal instructions here and throughout this document.

PART I - DESCRIPTION OF THE INVENTION

1. SUBMITTER(s): (First/initial/last)

Darrell C. West, Michael J. Paulus, Gerald A. Tuskan, Rupert Wimmer

2. TITLE: (10 words maximum)

Measurement of Wood/Plant Cell or Composite Material Attributes with Computer Assisted Tomography

3. BRIEF DESCRIPTION OF THE INVENTION:

Computer Assisted Tomography (CT) scanning techniques allow direct measurements of wood cell-wall thickness, cell diameter, and cell-vacuole diameter. The system described here consists of a fixed X-ray source, an X-ray detector, and a rotating sample stage. The sample is subjected to a cone beam of X-rays which serves to magnify the image projected into an area detector. The digital image of X-ray attenuation can then be analyzed in either a two- or three-dimensional space. Since the degree of attenuation is a function of material density, quantification is possible for the solid material of the cell wall and the air space (vacuole) within each cell. The digit output and reconstructed images from this approach allows measurements of wood-cell attributes (see Fig. 1).

4. BACKGROUND: (Problem your invention solves)

In pine and hardwood tree species, which are frequently used for pulp, paper and forest products, plant cells form rapid cell walls surrounding an empty vacuole, which can vary in diameter from 10 to 50 um. Within an annual growth cycle, large-diameter, thin-walled cells are produced at the beginning of the growing season, while smaller-diameter, thicker-walled cells are produced near the end of the growing season, thus producing "annual rings." In addition to variation within a given year's growth, wood cell anatomy varies from year to year. The wood formed during the earlier years of growth and near the crown of a tree is called "juvenile" wood and typically has lower density and shorter, thinner-walled fibers than mature wood. Because final paper and/or lumber quality is determined by cell wall attributes, improving wood quality is an important endeavor.

Cell-length and cell-wall-thickness measurements are currently made with standard visual microscopic techniques. However, sample preparation during traditional cell-wall-thickness studies requires several meticulous laboratory steps, including softening and maceration of the wood and microscope slide preparation. Such preparations inadvertently affect the obtained measures.
In addition to being cumbersome, cell-length data obtained by the traditional method contain errors because they include measurements of truncated cells produced by the preparation process. Furthermore, large sample-preparation and data-analysis time requirements limit the usefulness of the traditional cell-size-determination procedure in genetic selection studies in which hundreds of samples need to be processed as quickly as possible. The methodology proposed here eliminates the physical, chemical, and visual steps in the laboratory, thus accelerating and simplifying the data-acquisition process and cell attribute determinations.

5. DETAILED DESCRIPTION OF THE INVENTION: (How to make and use, method steps, best mode, drawings of all embodiments)

METHODOLOGY

The resolution and field of view of an X-ray CT system are determined primarily by the X-ray tube focal spot size, the spatial resolution of the X-ray source, and the system geometry. A generic representation of these parameters is presented in Figure 2. As previously configured, the ORNL imaging system was optimized for whole-body mouse scans with a reconstructed image resolution of approximately 100 microns full width, at half maximum (FWHM) and a minimum detectable feature size of about 50 microns.

Image resolution in radiographic systems is frequently defined in terms of the "modulation transfer function" (MTF), which is essentially the frequency (Fourier) domain representation of the spatial resolution. An advantage of MTF analysis is that multiple contributors to the overall spatial resolution may be analyzed independently; the overall resolution is then the frequency-domain product of the individual components.

Results from this reconfigured prototype indicated that a 12-micron resolution, through the use of an X-ray source with a smaller focal spot size and by adjustment of the geometry to ensure that the X-ray focal spot size is the dominant component of the MTF, is achievable. In this high-resolution configuration, the field of view has been reduced to approximately 2.5 mm, but the resolution and field of view is suited for direct measurement of wood cell diameter, cell-wall thickness, and vacuole width. The reconstructed image is approximately 12 um FWHM.

Because cell lumin diameter is greater than the image resolution, this cell dimension is measured directly from the image. Cell-wall thickness is considerably less than the image resolution, thus the average cell-wall thickness is determined by counting the number of cells per unit area, measuring the mean image density, and employing a priori knowledge of the radio-density of the cell wall.

The following is a step-wise progression of procedures used for measuring cell-wall diameter, cell-wall thickness, and vacuole diameter using X-ray Micro-CT:

1. Micro CT images are acquired using a rotating-state micro CT system with resolution of ~10 microns. The system uses a 1024 x 1024 element detector with a field of view of 5.5 mm.

2. Reconstruct a 2-dimensional 1024 x 1024 pixel image slice. Each pixel in the image is 5.4 x 5.4 microns.

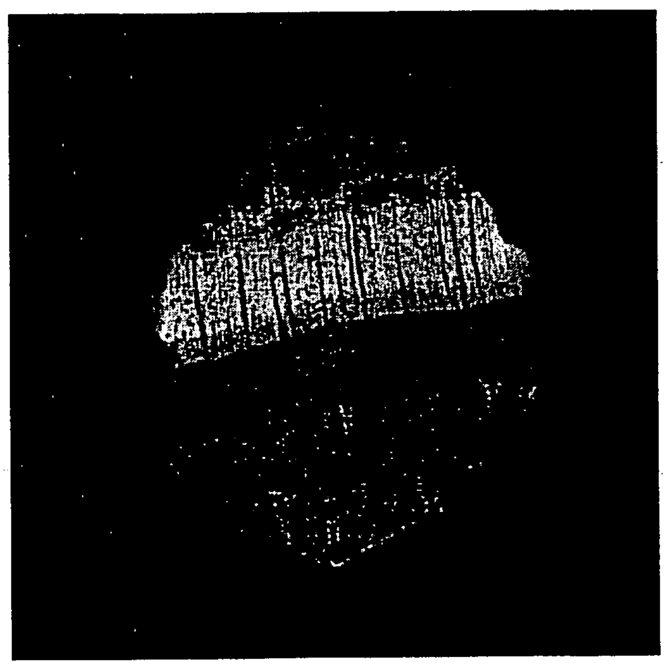

Figure 1. Representative micro CT reconstructed image.

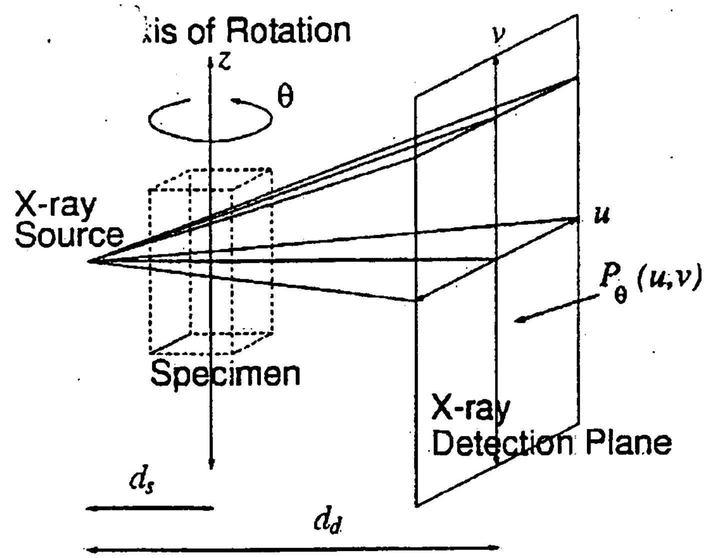

Figure 2. Conceptual representation of the generic configuration of x-ray source, focal spot, and system geometry as it affect spatial resolution.

3. Determine the number of cells per unit length for ~20 radial cell rows (Fig. 3). Determine mean cell size in this dimension.

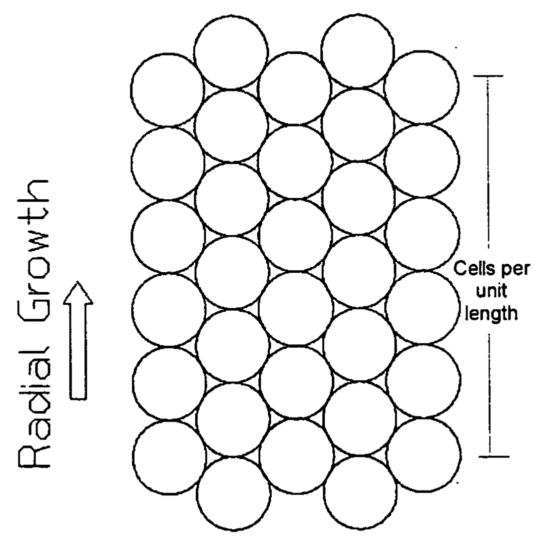

Figure 3. Radial orientation of cell size measurement.

4. Determine the number of tangential rows per unit length (Fig. 4). Determine mean cell size in this dimension.

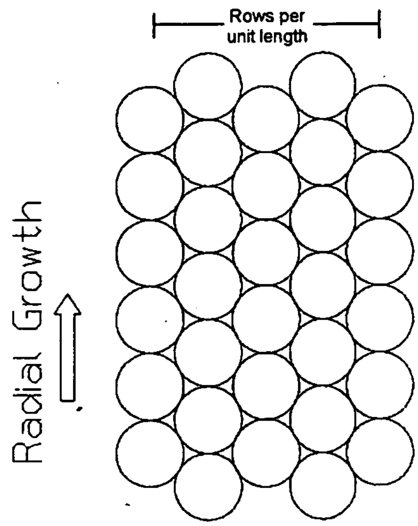

Figure 4. Tangential orientation of cell size measurement.

5. Model the cell as a hexagon with an effective size (flat-to-flat) equal to the average of the radial and tangential cell sizes and with a circular vacuole (Fig. 5).

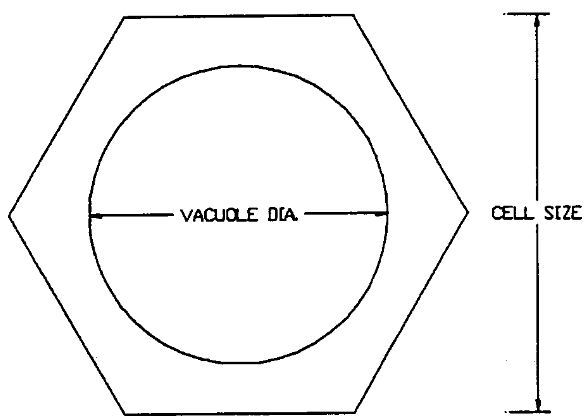

Figure 5. Assumed generic cell geometry.

6. Assume the average radio-density (D_{avg}) may be expressed as:

$$D_{avg} = (A_vD_v + A_cD_c)/(A_v + A_c),$$

Where, A_v is the average vacuole area, D_v is the known radio-density of air, A_c is the average per-cell area of the cellulose cell walls, and D_c is the known radio-density of cellulose. Solve for the fractional areas of the vacuoles and cellulose.

7. Given the known cell size (Step 4) and known fractional areas (Step 6) calculate the vacuole diameter.

8. Calculate the cell wall thickness as the difference between the cell size and the vacuole diameter.

APPARATUS

An apparatus is claimed that will automatically perform all or some of the following functions to analyze wood samples.

1. Trim a raw sample to a size that fits within the field of view of the x-ray computed tomography system or other three-dimensional imaging system.

2. Acquire 3-dimensional image data using x-ray CT or some other imaging method.

3. Determine the average cell size by measuring the mean period (in two dimensions) of the cellular structure.

4. Determine the average cell wall thickness by measuring the mean density of the sample, calculating the ratio of the cell wall material volume to the lumen material, and fitting the ratio to the measured cell size.

5. Automatically determine the average cell length by either

   a. searching the entire image volume for cell ends and determining the number of cell ends per unit volume.

   b. searching one or more 2D image slices for cell ends and extrapolating to estimate the number of cell ends per unit volume.

IMPROVEMENTS

The current resolution is limited by the geometric relationship between the size of the detector array and the size of the X-ray source. Our prototype produces a functional resolution of ca. 12 um. It is technically feasible to achieve a resolution near 1-2 um. At this resolution estimates of cell length are obtainable. In addition, computation time associated with image could be reduced through two modifications to the current prototype. First, the response time of the detector array could be enhanced, shortening the time required to capture the X-ray density data. Second, the computer operating platform could be shifted from a PC base to a UNIX platform on a workstation or to a parallel computer platform.

6. RELATED TECHNOLOGY: (List all relevant publications, patents, etc. of yours and others, and submit a copy of each with this form.)

o ORNL

Micro CT of small animals (see attached papers)
Micro CT for wood ring analysis, Applied Biotechnology and Biochemistry (see attached papers)

o Elsewhere

X-ray computed tomography is a mature field in the medical community and has also been used to analyze the micro structure of soil, biological and other samples.

7. UNIQUE FEATURES: (List all features that distinguish the invention over the technology listed in Item 6.)

This is the first time that X-ray CT scan has achieved the above configuration. This is also the first, as a result of the configuration, that direct, non-distributed measures of plant cell wall dimensions are obtainable.

8. POSSIBLE ALTERNATIVE VERSIONS:

Alternate applications:

1. Determine the uniformity of wood chip orientation in composite materials by performing 2D and 3D Fourier analysis of the image volume.

2. Determine the volumetrically varying orientation of wood chips by performing 2D and 3D Fourier analysis of the image volume.

3. Determine the volumetrically varying wood-to-resin ratio in composite materials by measuring the x-ray attenuation coefficients or other related parameter in composite material samples.

4. Evaluate the defect density in wood and composite material samples through image analysis of the x-ray CT or other image data set.

5. Determine the void density in wood or composite material samples through image analysis of the x-ray CT or other image data set.

6. Determine the volume of moisture uptake in wood or composite material samples through image analysis of the x-ray CT or other image data set.

7. Extend all claims to include any fiber-resin composite materials.

9. PROBABLE USES: (Anticipated U.S. Government, Industry, foreign uses of the invention)

We have already described the Micro CT scan's possible use in measuring plant cell attributes such as cell diameter, cell lumin diamtere, cell wall thickness and cell length. This same instrument could be used to obtain physical measures from reconstituted wood products such as oriented strand board, medium density fiber board and exuded wood products. Our preliminary data indicates that measures of fiber orientation, fiber dimensions and fiber to air space measures in these products are feasible. These measured parameters related to product quality and product performance. Instruments could be used in a wide array of research settings -- government and industry wood product laboratories and academic laboratories addressing woody plant structure and function. Furthermore, we could envision the invention being used in production settings to provide real-time quality information on wood and fiber-resin composite products. As such, it could be used in solid timber production facilities, reconstituted wood product facilities, and other fiber-resin production facilities.

PART II - FACTS RELATING TO THE INVENTION

10. REDUCTION TO PRACTICE : Select one of the following responses:

- ☐ Invention is purely conceptual and needs experimentation to validate the concept.
- ☐ Invention is conceptual, but does not need experimentation to validate the concept.
- ☐ Proof-of-principle experiment has been performed to validate the concept.
- ☒ Invention has been demonstrated on a [☐ laboratory; ☒ prototype; ☐ production] scale.
- ☐ Other (Explain):

11. SOURCE(S) OF FUNDS: (Funding under which the invention arose)

- ☐ DOE B&R Code:
- ☐ LDRD
- ☐ Other:
- ☐ 100% funds-in from third party identified below
- ☒ Seed Money

Identify respective Program Manager: Terry Sjoreen

12. THIRD PARTY: Is a third party involved in the invention? ☐ YES ☒ NO

If yes, provide the following information:

Note: A submitter who is not a UT-Battelle employee is a third party.

- ☐ CRADA
- ☐ Subcontract
- ☐ Interagency Agreement
- ☐ Work For Others
- ☐ No written agreement
- ☐ Other:

Name of third party:

Contract or Agreement No. Effective dates:

Explain any special circumstances:

13. SUBMITTERS: Each submitter must provide all the following information and original signature.

A. Full Name Darrell C. West SS#: 414-74-4623 Citizenship: USA

Residence Address: 2150 Phillips Road, Lenoir City, TN 37771 Telephone: 865-986-6470

Current Employer: ☐ *UT-Battelle* ☒ Other: Retired UT-Battelle

Employee No.: Work Address: Telephone: : - -

DIVISION No.: 42 Name: Environemtnal Sciences Manager: S. G. Hildebrand Supervisor: R. L.Graham

My specific contribution to the concept of the invention is: Project coordinator and initial conceptual development

Recorded in Notebook # Page(s) Date of Entry* Witnessed by:

Employer on *Date of Entry: ☐ *UT-Battelle* ☐ Other:

DIVISION No.: Name: Manager: Supervisor:

If Other, explain relationship to UT-Battelle and provide a copy of agreement, subcontract, or other documentation:

I have read and understood the contents of this document: Signature: NOT AVAILABLE FOR SIGNATURE Date: ________

B. Full Name Michael J. Paulus SS#: 410-13-7816 Citizenship: USA

Residence Address: 1516 Moorgate Drive, Knoxville, TN 37922 Telephone: 865- -

Current Employer: ☒ *UT-Battelle* ☐ Other:

Employee No.: 36220 Work Address: MS-6006 Telephone: : 865-241-4802

DIVISION No.: 9 Name: Instrumentation and Controls Manager: W. L. Bryan Supervisor: W.L. Bryan

My specific contribution to the concept of the invention is: Expertise in CT x-ray densitometry

Recorded in Notebook # A-107984-G Page(s) 40-45 Date of Entry* 2/12/2001 Witnessed by: M.L. Simpson and R.L Graham

Employer on *Date of Entry: ☒ *UT-Battelle* ☐ Other:

DIVISION No.: Name: Manager: Supervisor:

If Other, explain relationship to UT-Battelle and provide a copy of agreement, subcontract, or other documentation:

I have read and understood the contents of this document: Signature: NOT AVAILABLE FOR SIGNATURE Date: ________

C. Full Name Gerald A. Tuskan SS#: 526-23-6899 Citizenship: USA

Residence Address: 120 Newridge Road, Oak Ridge., TN Telephone: 865-481-8346

Current Employer: ☒ *UT-Battelle* ☐ Other:

Employee No.: 30576 Work Address: MS-6422 Telephone: : 865-576-8141

DIVISION No.: 42 Name: Environemntal Sciences Manager: S. G. Hildebrand Supervisor: R. Graham

My specific contribution to the concept of the invention is: Initial conceptual contributions and biological applications.

Recorded in Notebook # Page(s) Date of Entry* Witnessed by:

Employer on *Date of Entry: ☐ *UT-Battelle* ☐ Other:

DIVISION No.: Name: Manager: Supervisor:

If Other, explain relationship to UT-Battelle and provide a copy of agreement, subcontract, or other documentation:

I have read and understood the contents of this document: Signature: Gerald A. Tuskan Date: 3/8/01

D. Full Name Rupert Wimmer SS#: 410-73-4347 Citizenship: Austria

Residence Address: Telephone: - -

Current Employer: ☐ *UT-Battelle* ☒ Other: See Attached Sheet

Employee No.: Work Address: See Attached Sheet Telephone: : - -

DIVISION No.: 42 Name: Environmental Sciences Manager: S. G. Hildebrand Supervisor: S. B. McLaughlin

My specific contribution to the concept of the invention is: Fourier Analysis of density data for oriented strand board.

Recorded in Notebook # Page(s) Date of Entry* Witnessed by:

Employer on *Date of Entry: ☐ *UT-Battelle* ☐ Other:

DIVISION No.: Name: Manager: Supervisor:

If Other, explain relationship to UT-Battelle and provide a copy of agreement, subcontract, or other documentation:

I have read and understood the contents of this document: Signature: NOT AVAILABLE FOR SIGNATURE Date: ________

E Full Name SS#: - - Citizenship:

Residence Address: Telephone: - -

Current Employer: ☐ *UT-Battelle* ☐ Other:

Employee No.: Work Address: Telephone: : - -

DIVISION No.: *Name:* *Manager:* *Supervisor:*

My specific contribution to the concept of the invention is:

Recorded in Notebook # Page(s) Date of Entry* Witnessed by:

Employer on *Date of Entry: ☐ *UT-Battelle* ☐ Other:

DIVISION No.: *Name:* *Manager:* *Supervisor:*

If Other, explain relationship to UT-Battelle and provide a copy of agreement, subcontract, or other documentation:

I have read and understood the contents of this document: Signature: ______________________________ Date: _________

F. Full Name SS#: - - Citizenship:

Residence Address: Telephone: - -

Current Employer: ☐ *UT-Battelle* ☐ Other:

Employee No.: Work Address: Telephone: : - -

DIVISION No.: *Name:* *Manager:* *Supervisor:*

My specific contribution to the concept of the invention is:

Recorded in Notebook # Page(s) Date of Entry* Witnessed by:

Employer on *Date of Entry: ☐ *UT-Battelle* ☐ Other:

DIVISION No.: *Name:* *Manager:* *Supervisor:*

If Other, explain relationship to UT-Battelle and provide a copy of agreement, subcontract, or other documentation:

I have read and understood the contents of this document: Signature: ______________________________ Date: _________

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14. NOTEBOOK RECORDS : All items must be accurately completed. An inventor cannot be a witness.

EVENT	DATE	NOTEBOOK NO.	PAGES	TWO NOTEBOOK WITNESSES	WITNESS DATES
Original Concept	2/12/2001	A-107984-G	40-45	1. Michael L. Simpson	2/14/2001
				2. Robin L. Graham	2/14/2001
First Sketch or Drawing	2/12/2001	A-107984-G	40-45	1. Michael L. Simpson	2/14/2001
				2. Robin L. Graham	2/14/2001
First Written Description	2/12/2001	A-107984-G	40-45	1. Michael Simpson	2/14/2001
				2. Robin L. Graham	2/14/2001
First Model or Test Unit	2/12/2001	A-107984-G	40-45	1. Michael Simpson	2/14/2001
				2. Robin L. Graham	2/14/2001
First Test of Invention	2/12/2001	A-107984-G	40-45	1. Michael L. Simpson	2/14/2001
				2. Robin L. Graham	2/14/2001

List any other permanent records of the invention:

Please submit with this form copies of notebook entries and other records and reports relating to the invention. These documents may be essential in determining inventorship and date of the invention.

---

15. PUBLICATION STATUS: Has the invention been disclosed to the public or any party outside DOE and UT-Battelle?

☐YES ☒ NO

If yes, provide the following information:

Was the disclosure cleared through the Technical Information Office? ☐YES (attach copy of clearance form) ☐NO

Indicate the form(s) of the disclosure: ☐Oral ☐Visuals ☐Abstract ☐Full Article ☐Other

☐Submitted for review, but not yet published

Date of Conference or Publication: Location of Conference: Journal:

Other relevant information

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16. ROUTINE USE OF THE INVENTION:

If the inventors have tested any embodiment of the invention, has there been any additional, routine use of the invention?

☐YES ☒NO

If yes indicate date and circumstances of first such use:

PART III - MANAGEMENT REVIEW: (To be completed by submitter's supervisor, division management, or program manager)

17. Invention Achievement: This invention represents a
☐ Pioneer Breakthrough ☒ Major Improvement ☐ Minor Improvement

18. Claims and Enforceability: (check all that apply)

The invention is a:	☒ Method	☒ Product	☒ Machine	☐ Composition of Matter
Is the invention detectable in a product?	☒ Yes	☐ Somewhat	☒ No (can be practiced in secret)	
Scope of the invention is:	☒ Broad	☐ Intermediate	☐ Narrow	
Discovery by another is likely in:	☐ 1 year	☒ 3 years	☐ 5 years	
"Inventing around" the invention would be:	☐ Easy	☒ Moderate	☐ Difficult	

19. Quality of Description:
☐ Description, documentation, data, drawings, etc. are complete.
☒ Description is reasonably complete.
☐ Further information is needed to support a patent application.

20. Potential Use of the Invention:
☐ U.S. Government only ☒ Manufacturer ☒ Consumer
☒ U.S.A. Companies: Forest Products Industry, Teaching and Research
Products: Wood, Paper, and Fiber Products
☒ Foreign Countries: U.S., All Europe, Brazil, South Africa
Companies:

21. Market Value of the Invention:
Estimated total U.S. market: Present: \$13M 5 years \$700M
Estimated total world market: Present: \$25M 5 years \$1.25B
Use by others (1-10) + Near-term potential (1-10) + Value to related invention disclosures (1-10) = Total (≤30)

(+ +) = ☐

22. Recommended Disposition:
☒ UT-Battelle should elect and file patent application. ☐ Program or division will finance patent application.
☐ DOE should file patent application. ☐ Do not file a patent application.

23. Reviewer Comments:

Reviewer Name, printed or typed: Robin L. Graham Position: Section Head
Reviewer Signature: Robin Lambert Graham Date: 3-7-01

24. CLASSIFICATION: (To be completed by classification officer, or derivative classifier if not DUSA)
This document is properly classified as:
☐ Confidential ☐ Secret ☐ Restricted Data ☐ Formerly Restricted Data ☐ National Security Information
☒ Unclassified (Contains no classified information) ☐ **DUSA (no signature required)**
Signature: David R Hamrin Date: 3/8/01

25. RECEIPT BY INTELLECTUAL PROPERTY SECTION: ***(This form must be complete in order to be accepted.)***
Received by: Shelley L. Spafford Date: 3.13.01

CONFIDENTIAL INFORMATION
This document contains patentable subject matter and is disclosed in confidence by UT-Battelle, LLC under 35 USC § 205.

13. D. Full Name: Rupert Wimmer SS#: 410-73-4347 Citizenship: Austria

Current Employer: Institute of Botany, University of Agricultural Science Vienna

Work Address: Gregor Mendelstrasse 33, A-1180, Vienna, Austria

Subject: Micro CT for Wood Anatomy Studies

Date: Feb 12 2001

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE, LLC
FOR THE U.S. DEPARTMENT OF ENERGY

REPORT OF POSSIBLE SUBJECT INVENTION

ORNL-40 Electronically fillable in WORD 97 or newer (04/01/2000)

Intellectual Property Section Use Only
Disclosure No. ______
DOE S- ______

INSTRUCTIONS: Place pointer over highlighted text to reveal instructions here and throughout this document.[JM1]

PART I - DESCRIPTION OF THE INVENTION

1. SUBMITTER(s): [JM2] (First/initial/last)

Darrell C. West, Michael J. Paulus, Gerald A. Tuskan

2. TITLE: [JM3] (10 words maximum)

Measurement of Wood/Plant Cell Attributes with Computer Assisted Tomography

3. BRIEF DESCRIPTION OF THE INVENTION:[JM4]

Computer Assisted Tomography (CT) scanning techniques allow direct measurements of wood cell-wall thickness, cell diameter, and cell-vacuole diameter. The system described here consists of a fixed X-ray source, an X-ray detector, and a rotating sample stage. The sample is subjected to a cone beam of X-rays which serves to magnify the image projected into an area detector. The digital image of X-ray attenuation can then be analyzed in either a two- or three-dimensional space. Since the degree of a attenuation is a function of material density, quantification is possible for the solid material of the cell wall and the air space (vacuole) within each cell. The digit output and reconstructed images from this approach allows measurements of wood-cell attributes (see Fig. 1).

4. BACKGROUND: [JM5] (Problem your invention solves)

In pine and hardwood tree species, which are frequently used for pulp, paper and forest products, plant cells form rapid cell walls surrounding an empty vacuole which can vary in diameter from 10 to 50 um. Within an annual growth cycle, large-diameter, thin-walled cells are produced at the beginning of the growing season, while smaller-diameter, thicker-walled cells are produced near the end of the growing season, thus producing "annual rings." In addition to variation within a given year's growth, wood cell anatomy varies from year to year. The wood formed during the earlier years of growth and near the crown of a tree is called "juvenile" wood and typically has lower density and shorter, thinner-walled fibers than mature wood. Because final paper and/or lumber quality is determined by cell wall attributes, improving wood quality is an important endeavor.

Cell-length and cell-wall-thickness measurements are currently made with standard visual microscopic techniques. However, sample preparation during traditional cell-wall-thickness studies requires several meticulous laboratory steps, including softening and maceration of the wood and microscope slide preparation. Such preparations inadvertently affects the obtained measures. In addition to being cumbersome, cell-length data obtained by the traditional method contain errors because they include measurements of truncated cells produced by the preparation process. Furthermore, large sample-preparation and data-analysis time requirements limit the usefulness of the traditional cell-size-determination procedure in genetic selection studies in which hundreds of samples need to be processed as quickly as possible. The methodology proposed here eliminates the physical, chemical, and visual steps in the laboratory, thus accelerating and simplifying the data-acquisition process and cell attribute determinations.

5. DETAILED DESCRIPTION OF THE INVENTION:[JM6] (How to make and use, method steps, best mode, drawings of all embodiments)

The resolution and field of view of a X-ray CT system are determined primarily by the X-ray tube focal spot size, the spatial resolution of the X-ray source, and the system geometry. A generic representation of these parameters is presented in Figure 2. As previously configured, the ORNL imaging system was optimized for whole-body mouse scans with a reconstructed image resolution of approximately 100 microns full width, at half maximum (FWHM) and a minimum detectable feature size of about 50 microns.

Image resolution in radiographic systems is frequently defined in terms of the "modulation transfer function" (MTF), which is essentially the frequency (Fourier) domain representation of the spatial resolution. An advantage of MTF analysis is that multiple

Michael J Paulus Feb 12, 2001
Gerald Tuskan 2/14/01
Robin L Graham 2/14/01

Continued on page 41

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Read and understood by Michael J. [illegible] Date 2-14-01
Badge 34325

Subject: Micro CT for Wood Anatomy Studies

Date: Feb 12 2001 (Month Day Year)

contributors to the overall spatial resolution may be analyzed independently; the overall resolution is then the frequency-domain product of the individual components.

Results from this reconfigured prototype indicated that a 12-micron resolution, through the use of an X-ray source with a smaller focal spot size and by adjustment of the geometry to ensure that the X-ray focal spot size is the dominant component of the MTF, is achievable. In this high-resolution configuration, the field of view has been reduced to approximately 2.5 mm, but the resolution and field of view is suited for direct measurement of wood cell diameter, cell-wall thickness, and vacuole width. The reconstructed image is approximately 12 um FWHM.

Because cell lumin diameter is greater than the image resolution, this cell dimension is measured directly from the image. Cell-wall thickness is considerably less than the image resolution, thus the average cell-wall thickness is determined by counting the number of cells per unit area, measuring the mean image density, and employing a priori knowledge of the radio-density of the cell wall.

The following is a step-wise progression of procedures used for measuring cell-wall diameter, cell-wall thickness, and vacuole diameter using X-ray Micro-CT:

1. MicroCT images are acquired using a rotating-state microCT system with resolution of ~10 microns. The system uses a 1024 x 1024 element detector with a field of view of 5.5 mm.

2. Reconstruct a 2-dimensional 1024 x 1024 pixel image slice. Each pixel in the image is 5.4 x 5.4 microns.

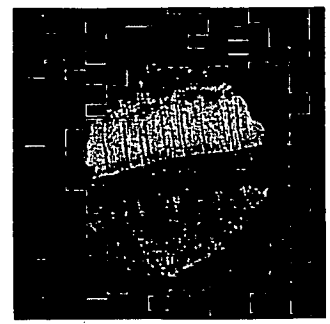

Figure 1. Representative micro CT reconstructed image.

2

Michael J Paulus Feb 12, 2001
Robin L Graham 2/14/01
Gerald A Tuskan 2/14/01

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Continued on page 42

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EXHIBIT
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Subject Micro CT for Wood Anatomy Studies

Date FEB 12, 2007 ~~19~~
Month Day Year

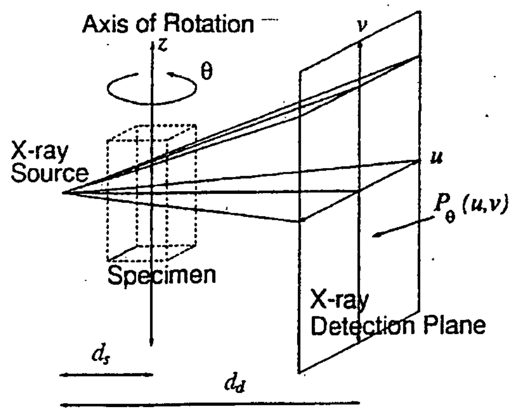

Figure 2. Conceptual representation of the generic configuration of x-ray source, focal spot, and system geometry as it affect spatial resolution.

3. Determine the number of cells per unit length for ~20 radial cell rows (Fig. 3). Determine mean cell size in this dimension.

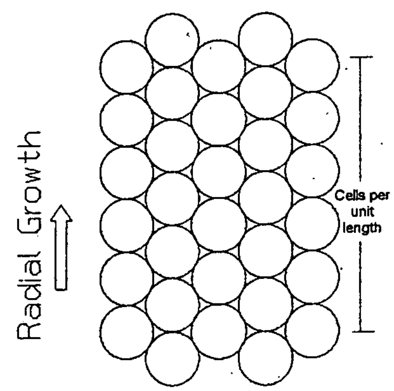

Figure 3. Radial orientation of cell size measurement.

FEB 12, 2007

2-14-01

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CONFIDENTIAL INFORMATION
This document contains patentable subject matter and is disclosed in confidence by UT-Battelle, LLC under 35 USC § 205.

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Continued on page 43

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Badge 34385

Subject Microct for Wood Anatomy Studies

Date FEB 12, 2001 ~~19~~
Month Day Year

4. Determine the number of tangential rows per unit length (Fig. 4). Determine mean cell size in this dimension.

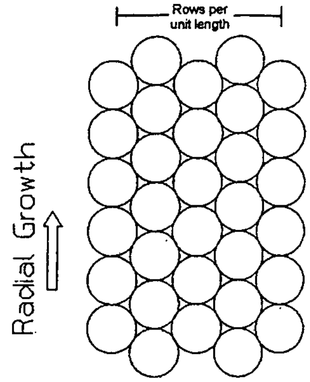

Figure 4. Tangential orientation of cell size measurement.

5. Model the cell as a hexagon with an effective size (flat-to-flat) equal to the average of the radial and tangential cell sizes and with a circular vacuole (Fig. 5).

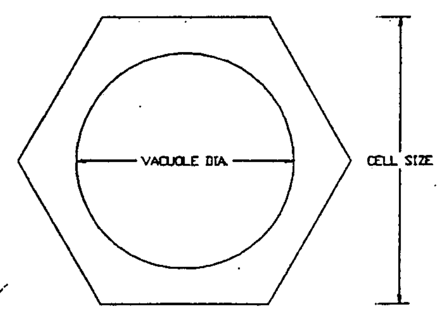

Figure 5. Assumed generic cell geometry.

Michael J Paul
FEB 12, 2001
Robin L Graham 2/14/01
Donald Todd
2/14/01

CONFIDENTIAL INFORMATION

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Continued on page 44

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Read and understood by Date 2/14/01

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Subject Micro CT for Wood Anatomy Studies

Date Feb 12, 2001 ~~19~~
Month Day Year

6. Assume the average radio-density (D_{avg}) may be expressed as:

$$D_{avg} = (A_v D_v + A_c D_c)/(A_v + A_c),$$

Where, A_v is the average vacuole area, D_v is the known radio-density of air, A_c is the average per-cell area of the cellulose cell walls, and D_c is the known radio-density of cellulose. Solve for the fractional areas of the vacuoles and cellulose.

7. Given the known cell size (Step 4) and known fractional areas (Step 6) calculate the vacuole diameter.

8. Calculate the cell wall thickness as the difference between the cell size and the vacuole diameter.

6. RELATED TECHNOLOGY:[JM7] (List all relevant publications, patents, etc. of yours and others, and submit a copy of each with this form

Mike you will have to complete this section.

7. UNIQUE FEATURES: [JM8] (List all features that distinguish the invention over the technology listed in Item 6.)

This is the first time that X-ray CT scan has achieved the above configuration. This is also the first, as a result of the configuration, that direct, non-distributed measures of plant cell wall dimensions are obtainable.

8. POSSIBLE ALTERNATIVE VERSIONS:[JM9]

The current resolution is limited by the geometric relationship between the size of the detector array and the size of the X-ray source. Our prototype produces a functional resolution of ca. 12 um. It is technically feasible to achieve a resolution near 1-2 um. At this resolution estimates of cell length are obtainable. In addition, computation time associated with image could be reduced through two modifications to the current prototype. First, the response time of the detector array could be enhanced, shortening the time required to capture the X-ray density data. Second, the computer operating platform could be shifted from a PC base to a UNIX platform on a workstation or to a parallel computer platform. This would require some codes to be re-written.

9. PROBABLE USES: [JM10] (Anticipated U.S. Government, Industry, foreign uses of the invention)

We have already described the Micro-CT scans possible use in measuring plant cell attributes such as cell diameter, cell lumin diamtere, cell wall thickness and cell length. This same instrument could be used to obtain physical measures from reconstituted wood products such as oriented strand board, medium density fiber board and exuded wood products. Our preliminary data indicates that measures of fiber orientation, fiber dimensions and fiber to air space measures in these products are feasible. These measured parameters related to product quality and product performance.

Robert Graham 2/14/01

Feb 12, 2001

2/14/01

CONFIDENTIAL INFORMATION

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Continued on page 45

2-14-01

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Subject MicroCT for Wood Anatomy Studies

Date Feb 12, 2001 ~~19~~
Month Day Year

Apparatus

An apparatus is claimed that will automatically perform all or some of the following functions to analyze wood samples.

1. Trim a raw sample to a size that fits within the field of view of the x-ray computed tomography system or other three-dimensional imaging system.

2. Acquire 3-dimensional image data using x-ray CT or some other imaging method.

3. Determine the average cell size by measuring the mean period (in two dimensions) of the cellular structure.

4. Determine the average cell wall thickness by measuring the mean density of the sample, calculating the ratio of the cell wall material volume to the lumen material, and fitting the ratio to the measured cell size.

5. Automatically determine the average cell length by either

   a. searching the entire image volume for cell ends and determining the number of cell ends per unit volume.

   b. searching one or more 2D image slices for cell ends and extrapolating to estimate the number of cell ends per unit volume.

Alternate applications:

1. Determine the uniformity of wood chip orientation in composite materials by performing 2D and 3D Fourier analysis of the image volume.

2. Determine the volumetrically varying orientation of wood chips by performing 2D and 3D Fourier analysis of the image volume.

3. Determine the volumetrically varying wood-to-resin ratio in composite materials by measuring the x-ray attenuation coefficients or other related parameter in composite material samples.

4. Evaluate the defect density in wood and composite material samples through image analysis of the x-ray CT or other image data set.

5. Determine the void density in wood or composite material samples through image analysis of the x-ray CT or other image data set.

6. Determine the volume of moisture uptake in wood or composite material samples through image analysis of the x-ray CT or other image data set.

Feb 12, 2001

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LAST PAGE OF THIS ENTRY

Continued on page

Recorded by Date

Read and understood by Date 2-14-01

34385

UCN-6201

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re: Application of WEST et al.

Application No.: 10/029,098 Examiner: Bruce, David V.

Date Filed: December 20, 2001 Group: 2882

For: MEASUREMENT OF WOOD/PLANT CELL OR COMPOSITE MATERIAL ATTRIBUTES WITH COMPUTER ASSISTED TOMOGRAPHY

CERTIFICATE UNDER 37 CFR 1.8(a)
I hereby certify that this correspondence is being deposited with the U.S. Postal Service as First Class mail in an envelope addressed to the Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450 on 12/22/03.

_______________ Reg. No. 46,803
Neil R. Jetter

DECLARATION UNDER 37 C.F.R. §1.131

Box Non-Fee Amendment
Commissioner for Patents
P.O. box 1450
Alexandria, VA 22313-1450

Sir:

I, Rupert Wimmer, declare:

1. I am a named inventor of the subject matter claimed in the above-captioned application.

2. I have read the Office Action mailed October 14, 2003, and the references cited therein.

3. I have been employed by Institute of Botany, University of Agricultural Science Vienna since before February 2001.

4. I was one of the inventors which conceived of the above-entitled invention in the United States prior to the earliest effective filing date of February 23, 2001 that I have been advised may be afforded to U.S. Pat. No. 6,597,761 B1 to Garms, III.

5. Before February 23, 2001, I, along with my co-inventors, conceived of the claimed subject matter. An Invention Disclosure which describes the claimed invention was submitted to the management at the Oak Ridge National Laboratory and dated between March 7, 2001 and March 13, 2001. The Invention Disclosure is attached hereto and marked as Exhibit "B".

Declarant further states that all statements made herein are of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under §1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Date: December 15, 2003

Rupert Wimmer

{WP158285;1}

INVENTION DISCLOSURE
FROM
UT-BATTELLE, LLC

DOE CASE NO.: S- 96,692 **DISCLOSURE NO.: 0934**

SUBMITTED BY: Darrell C. West, Michael J. Paulus, Gerald A. Tuskan and Rupert Wimmer*

TITLE: Measurement of Wood/Plant Cell or Composite Material Attributes with Computer Assisted Tomography

BRIEF DESCRIPTION OF THE INVENTION: The subject invention disclosed herein is a method for measuring cell dimensions, such as cell length, cell diameter and cell wall thickness, of wood and plant cells or other composite material using computer assisted tomography. The existing ORNL rotating-state Micro CT imaging system has been modified and improved by modifying the x-ray tube focal spot size and the system geometry. The system and method of the subject invention are also used to obtain physical measures from reconstituted wood products such as oriented strand board, medium density fiber board and exuded wood products. The measured parameters relate to product quality and product performance. The method and system of the subject invention can be used in production settings to provide real-time quality information on wood and fiber-resin composite products. As such, it can be used in solid timber production facilities, reconstituted wood product facilities, and other fiber-resin production facilities.

Non-enabling title and abstract of the invention: same

DESCRIPTION OF THE INVENTION:
A description of the subject invention, related art, pertinent facts are set forth in the appended Report of Possible Subject Invention.
This invention is related to the following earlier disclosures:

1. ERID 0429 (S-88,699), patent application pending
2. ERID 0521 (S-90,811), patent application pending

POTENTIAL RIGHTS ISSUES:
There does not appear to be any third party involvement in the invention.
The invention does not appear to be subject to an "exceptional circumstance" as defined by the Prime Contract between UT-Battelle and the DOE.

*Visiting scientist on leave from Austrian Agricultural University; Not subject to 35 USC 212 nor 35 USC 202; assigned rights to ORNL

REMARKS:
It appears that: sufficient information is available to form the basis for a patent application; the invention appears to be distinct from known prior art; there is no potential U.S. statutory bar nor potential foreign bar.

Patent Agent: SLS

EXHIBIT
tabbies
"B"

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE, LLC
FOR THE U.S. DEPARTMENT OF ENERGY

Intellectual Property Section Use Only
Disclosure No. 0934
DOE S-96,692

REPORT OF POSSIBLE SUBJECT INVENTION

ORNL-40 *Electronically fillable in WORD 97 or newer* (04/01/2000)

INSTRUCTIONS: Place pointer over highlighted text to reveal instructions here and throughout this document.

PART I - DESCRIPTION OF THE INVENTION

1. SUBMITTER(s): (First/initial/last)

Darrell C. West, Michael J. Paulus, Gerald A. Tuskan, Rupert Wimmer

2. TITLE: (10 words maximum)

Measurement of Wood/Plant Cell or Composite Material Attributes with Computer Assisted Tomography

3. BRIEF DESCRIPTION OF THE INVENTION:

Computer Assisted Tomography (CT) scanning techniques allow direct measurements of wood cell-wall thickness, cell diameter, and cell-vacuole diameter. The system described here consists of a fixed X-ray source, an X-ray detector, and a rotating sample stage. The sample is subjected to a cone beam of X-rays which serves to magnify the image projected into an area detector. The digital image of X-ray attenuation can then be analyzed in either a two- or three-dimensional space. Since the degree of attenuation is a function of material density, quantification is possible for the solid material of the cell wall and the air space (vacuole) within each cell. The digit output and reconstructed images from this approach allows measurements of wood-cell attributes (see Fig. 1).

4. BACKGROUND: (Problem your invention solves)

In pine and hardwood tree species, which are frequently used for pulp, paper and forest products, plant cells form rapid cell walls surrounding an empty vacuole, which can vary in diameter from 10 to 50 um. Within an annual growth cycle, large-diameter, thin-walled cells are produced at the beginning of the growing season, while smaller-diameter, thicker-walled cells are produced near the end of the growing season, thus producing "annual rings." In addition to variation within a given year's growth, wood cell anatomy varies from year to year. The wood formed during the earlier years of growth and near the crown of a tree is called "juvenile" wood and typically has lower density and shorter, thinner-walled fibers than mature wood. Because final paper and/or lumber quality is determined by cell wall attributes, improving wood quality is an important endeavor.

Cell-length and cell-wall-thickness measurements are currently made with standard visual microscopic techniques. However, sample preparation during traditional cell-wall-thickness studies requires several meticulous laboratory steps, including softening and maceration of the wood and microscope slide preparation. Such preparations inadvertently affect the obtained measures.
In addition to being cumbersome, cell-length data obtained by the traditional method contain errors because they include measurements of truncated cells produced by the preparation process. Furthermore, large sample-preparation and data-analysis time requirements limit the usefulness of the traditional cell-size-determination procedure in genetic selection studies in which hundreds of samples need to be processed as quickly as possible. The methodology proposed here eliminates the physical, chemical, and visual steps in the laboratory, thus accelerating and simplifying the data-acquisition process and cell attribute determinations.

5. DETAILED DESCRIPTION OF THE INVENTION: (How to make and use, method steps, best mode, drawings of all embodiments)

METHODOLOGY

The resolution and field of view of an X-ray CT system are determined primarily by the X-ray tube focal spot size, the spatial resolution of the X-ray source, and the system geometry. A generic representation of these parameters is presented in Figure 2. As previously configured, the ORNL imaging system was optimized for whole-body mouse scans with a reconstructed image resolution of approximately 100 microns full width, at half maximum (FWHM) and a minimum detectable feature size of about 50 microns.

Image resolution in radiographic systems is frequently defined in terms of the "modulation transfer function" (MTF), which is essentially the frequency (Fourier) domain representation of the spatial resolution. An advantage of MTF analysis is that multiple contributors to the overall spatial resolution may be analyzed independently; the overall resolution is then the frequency-domain product of the individual components.

Results from this reconfigured prototype indicated that a 12-micron resolution, through the use of an X-ray source with a smaller focal spot size and by adjustment of the geometry to ensure that the X-ray focal spot size is the dominant component of the MTF, is achievable. In this high-resolution configuration, the field of view has been reduced to approximately 2.5 mm, but the resolution and field of view is suited for direct measurement of wood cell diameter, cell-wall thickness, and vacuole width. The reconstructed image is approximately 12 um FWHM.

Because cell lumin diameter is greater than the image resolution, this cell dimension is measured directly from the image. Cell-wall thickness is considerably less than the image resolution, thus the average cell-wall thickness is determined by counting the number of cells per unit area, measuring the mean image density, and employing a priori knowledge of the radio-density of the cell wall.

The following is a step-wise progression of procedures used for measuring cell-wall diameter, cell-wall thickness, and vacuole diameter using X-ray Micro-CT:

1. Micro CT images are acquired using a rotating-state micro CT system with resolution of ~10 microns. The system uses a 1024 x 1024 element detector with a field of view of 5.5 mm.

2. Reconstruct a 2-dimensional 1024 x 1024 pixel image slice. Each pixel in the image is 5.4 x 5.4 microns.

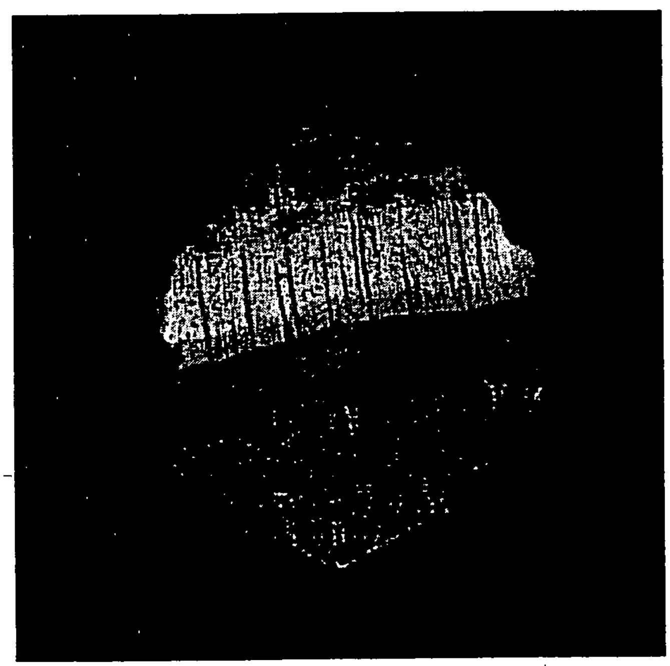

Figure 1. Representative micro CT reconstructed image.

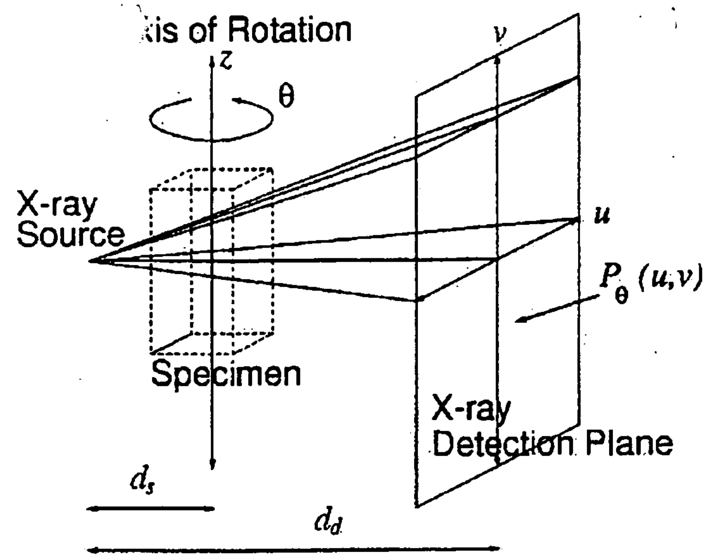

Figure 2. Conceptual representation of the generic configuration of x-ray source, focal spot, and system geometry as it affect spatial resolution.

3. Determine the number of cells per unit length for ~20 radial cell rows (Fig. 3). Determine mean cell size in this dimension.

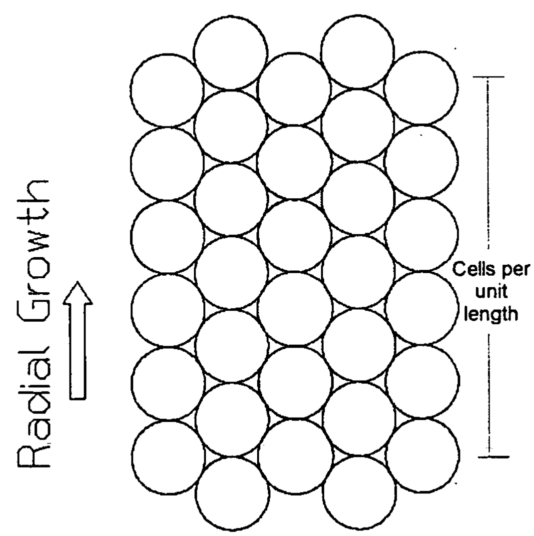

Figure 3. Radial orientation of cell size measurement.

4. Determine the number of tangential rows per unit length (Fig. 4). Determine mean cell size in this dimension.

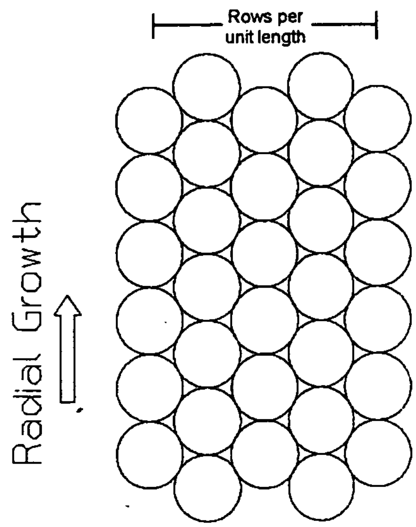

Figure 4. Tangential orientation of cell size measurement.

5. Model the cell as a hexagon with an effective size (flat-to-flat) equal to the average of the radial and tangential cell sizes and with a circular vacuole (Fig. 5).

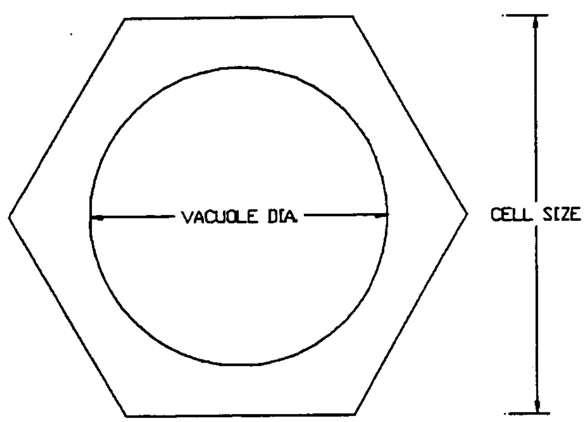

Figure 5. Assumed generic cell geometry.

6. Assume the average radio-density (D_{avg}) may be expressed as:

$$D_{avg} = (A_v D_v + A_c D_c)/(A_v + A_c),$$

Where, A_v is the average vacuole area, D_v is the known radio-density of air, A_c is the average per-cell area of the cellulose cell walls, and D_c is the known radio-density of cellulose. Solve for the fractional areas of the vacuoles and cellulose.

7. Given the known cell size (Step 4) and known fractional areas (Step 6) calculate the vacuole diameter.

8. Calculate the cell wall thickness as the difference between the cell size and the vacuole diameter.

APPARATUS

An apparatus is claimed that will automatically perform all or some of the following functions to analyze wood samples.

1. Trim a raw sample to a size that fits within the field of view of the x-ray computed tomography system or other three-dimensional imaging system.
2. Acquire 3-dimensional image data using x-ray CT or some other imaging method.
3. Determine the average cell size by measuring the mean period (in two dimensions) of the cellular structure.
4. Determine the average cell wall thickness by measuring the mean density of the sample, calculating the ratio of the cell wall material volume to the lumen material, and fitting the ratio to the measured cell size.
5. Automatically determine the average cell length by either
   a. searching the entire image volume for cell ends and determining the number of cell ends per unit volume.
   b. searching one or more 2D image slices for cell ends and extrapolating to estimate the number of cell ends per unit volume.

IMPROVEMENTS

The current resolution is limited by the geometric relationship between the size of the detector array and the size of the X-ray source. Our prototype produces a functional resolution of ca. 12 um. It is technically feasible to achieve a resolution near 1-2 um. At this resolution estimates of cell length are obtainable. In addition, computation time associated with image could be reduced through two modifications to the current prototype. First, the response time of the detector array could be enhanced, shortening the time required to capture the X-ray density data. Second, the computer operating platform could be shifted from a PC base to a UNIX platform on a workstation or to a parallel computer platform.

6. RELATED TECHNOLOGY: (List all relevant publications, patents, etc. of yours and others, and submit a copy of each with this form.)

o ORNL

Micro CT of small animals (see attached papers)
Micro CT for wood ring analysis, Applied Biotechnology and Biochemistry (see attached papers)

o Elsewhere

X-ray computed tomography is a mature field in the medical community and has also been used to analyze the micro structure of soil, biological and other samples.

7. UNIQUE FEATURES: (List all features that distinguish the invention over the technology listed in Item 6.)

This is the first time that X-ray CT scan has achieved the above configuration. This is also the first, as a result of the configuration, that direct, non-distributed measures of plant cell wall dimensions are obtainable.

8. POSSIBLE ALTERNATIVE VERSIONS:

Alternate applications:

1. Determine the uniformity of wood chip orientation in composite materials by performing 2D and 3D Fourier analysis of the image volume.

2. Determine the volumetrically varying orientation of wood chips by performing 2D and 3D Fourier analysis of the image volume.

3. Determine the volumetrically varying wood-to-resin ratio in composite materials by measuring the x-ray attenuation coefficients or other related parameter in composite material samples.

4. Evaluate the defect density in wood and composite material samples through image analysis of the x-ray CT or other image data set.

5. Determine the void density in wood or composite material samples through image analysis of the x-ray CT or other image data set.

6. Determine the volume of moisture uptake in wood or composite material samples through image analysis of the x-ray CT or other image data set.

7. Extend all claims to include any fiber-resin composite materials.

9. PROBABLE USES: (Anticipated U.S. Government, Industry, foreign uses of the invention)

We have already described the Micro CT scan's possible use in measuring plant cell attributes such as cell diameter, cell lumin diamtere, cell wall thickness and cell length. This same instrument could be used to obtain physical measures from reconstituted wood products such as oriented strand board, medium density fiber board and exuded wood products. Our preliminary data indicates that measures of fiber orientation, fiber dimensions and fiber to air space measures in these products are feasible. These measured parameters related to product quality and product performance. Instruments could be used in a wide array of research settings -- government and industry wood product laboratories and academic laboratories addressing woody plant structure and function. Furthermore, we could envision the invention being used in production settings to provide real-time quality information on wood and fiber-resin composite products. As such, it could be used in solid timber production facilities, reconstituted wood product facilities, and other fiber-resin production facilities.

PART II - FACTS RELATING TO THE INVENTION

10. REDUCTION TO PRACTICE : Select one of the following responses:

- ☐ Invention is purely conceptual and needs experimentation to validate the concept.
- ☐ Invention is conceptual, but does not need experimentation to validate the concept.
- ☐ Proof-of-principle experiment has been performed to validate the concept.
- ☒ Invention has been demonstrated on a [☐ laboratory; ☒ prototype; ☐ production] scale.
- ☐ Other (Explain):

11. SOURCE(S) OF FUNDS: (Funding under which the invention arose)

- ☐ DOE B&R Code:
- ☐ 100% funds-in from third party identified below
- ☐ LDRD
- ☒ Seed Money
- ☐ Other:

Identify respective Program Manager: Terry Sjoreen

12. THIRD PARTY: Is a third party involved in the invention? ☐ YES ☒ NO

If yes, provide the following information:

Note: A submitter who is not a UT-Battelle employee is a third party.

- ☐ CRADA
- ☐ Subcontract
- ☐ Interagency Agreement
- ☐ Work For Others
- ☐ No written agreement
- ☐ Other:

Name of third party:

Contract or Agreement No. Effective dates:

Explain any special circumstances:

13. SUBMITTERS: Each submitter must provide all the following information and original signature.

A. Full Name Darrell C. West SS#: 414-74-4623 Citizenship: USA

Residence Address: 2150 Phillips Road, Lenoir City, TN 37771 Telephone: 865-986-6470

Current Employer: ☐ *UT-Battelle* ☒ Other: Retired UT-Battelle

Employee No.: Work Address: Telephone: : - -

DIVISION No.: 42 Name: Environemtnal Sciences Manager: S. G. Hildebrand Supervisor: R. L.Graham

My specific contribution to the concept of the invention is: Project coordinator and initial conceptual development

Recorded in Notebook # Page(s) Date of Entry* Witnessed by:

Employer on *Date of Entry: ☐ *UT-Battelle* ☐ Other:

DIVISION No.: Name: Manager: Supervisor:

If Other, explain relationship to UT-Battelle and provide a copy of agreement, subcontract, or other documentation:

I have read and understood the contents of this document: Signature: NOT AVAILABLE FOR SIGNATURE Date: ________

B. Full Name Michael J. Paulus SS#: 410-13-7816 Citizenship: USA

Residence Address: 1516 Moorgate Drive, Knoxville, TN 37922 Telephone: 865- -

Current Employer: ☒ *UT-Battelle* ☐ Other:

Employee No.: 36220 Work Address: MS-6006 Telephone: : 865-241-4802

DIVISION No.: 9 Name: Instrumentation and Controls Manager: W. L. Bryan Supervisor: W.L. Bryan

My specific contribution to the concept of the invention is: Expertise in CT x-ray densitometry

Recorded in Notebook # A-107984-G Page(s) 40-45 Date of Entry* 2/12/2001 Witnessed by: M.L. Simpson and R.L Graham

Employer on *Date of Entry: ☒ *UT-Battelle* ☐ Other:

DIVISION No.: Name: Manager: Supervisor:

If Other, explain relationship to UT-Battelle and provide a copy of agreement, subcontract, or other documentation:

I have read and understood the contents of this document: Signature: NOT AVAILABLE FOR SIGNATURE Date: ________

C. Full Name Gerald A. Tuskan SS#: 526-23-6899 Citizenship: USA

Residence Address: 120 Newridge Road, Oak Ridge., TN Telephone: 865-481-8346

Current Employer: ☒ *UT-Battelle* ☐ Other:

Employee No.: 30576 Work Address: MS-6422 Telephone: : 865-576-8141

DIVISION No.: 42 Name: Environemntal Sciences Manager: S. G. Hildebrand Supervisor: R. Graham

My specific contribution to the <u>concept</u> of the invention is: Initial conceptual contributions and biological applications.

Recorded in Notebook # Page(s) Date of Entry* Witnessed by:

Employer on *Date of Entry: ☐ *UT-Battelle* ☐ Other:

DIVISION No.: Name: Manager: Supervisor:

If Other, explain relationship to UT-Battelle and provide a copy of agreement, subcontract, or other documentation:

I have read and understood the contents of this document: Signature: Gerald A. Tuskan Date: 3/8/01

D. Full Name Rupert Wimmer SS#: 410-73-4347 Citizenship: Austria

Residence Address: Telephone: - -

Current Employer: ☐ *UT-Battelle* ☒ Other: See Attached Sheet

Employee No.: Work Address: See Attached Sheet Telephone: : - -

DIVISION No.: 42 Name: Environmental Sciences Manager: S. G. Hildebrand Supervisor: S. B. McLaughlin

My specific contribution to the <u>concept</u> of the invention is: Fourier Analysis of density data for oriented strand board.

Recorded in Notebook # Page(s) Date of Entry* Witnessed by:

Employer on *Date of Entry: ☐ *UT-Battelle* ☐ Other:

DIVISION No.: Name: Manager: Supervisor:

If Other, explain relationship to UT-Battelle and provide a copy of agreement, subcontract, or other documentation:

I have read and understood the contents of this document: Signature: NOT AVAILABLE FOR SIGNATURE Date: ________

E Full Name SS#: - - Citizenship:

Residence Address: Telephone: - -

Current Employer: ☐ *UT-Battelle* ☐ Other:

Employee No.: Work Address: Telephone: : - -

DIVISION No.: *Name:* *Manager:* *Supervisor:*

My specific contribution to the concept of the invention is:

Recorded in Notebook # Page(s) Date of Entry* Witnessed by:

Employer on *Date of Entry: ☐ *UT-Battelle* ☐ Other:

DIVISION No.: *Name:* *Manager:* *Supervisor:*

If Other, explain relationship to UT-Battelle and provide a copy of agreement, subcontract, or other documentation:

I have read and understood the contents of this document: Signature: ______________________________ Date: _________

F. Full Name SS#: - - Citizenship:

Residence Address: Telephone: - -

Current Employer: ☐ *UT-Battelle* ☐ Other:

Employee No.: Work Address: Telephone: : - -

DIVISION No.: *Name:* *Manager:* *Supervisor:*

My specific contribution to the concept of the invention is:

Recorded in Notebook # Page(s) Date of Entry* Witnessed by:

Employer on *Date of Entry: ☐ *UT-Battelle* ☐ Other:

DIVISION No.: *Name:* *Manager:* *Supervisor:*

If Other, explain relationship to UT-Battelle and provide a copy of agreement, subcontract, or other documentation:

I have read and understood the contents of this document: Signature: ______________________________ Date: _________

---

14. NOTEBOOK RECORDS : All items <u>must</u> be accurately completed. An inventor <u>cannot</u> be a witness.

EVENT	DATE	NOTEBOOK NO.	PAGES	TWO NOTEBOOK WITNESSES	WITNESS DATES
Original Concept	2/12/2001	A-107984-G	40-45	1. Michael L. Simpson	2/14/2001
				2. Robin L. Graham	2/14/2001
First Sketch or Drawing	2/12/2001	A-107984-G	40-45	1. Michael L. Simpson	2/14/2001
				2. Robin L. Graham	2/14/2001
First Written Description	2/12/2001	A-107984-G	40-45	1. Michael Simpson	2/14/2001
				2. Robin L. Graham	2/14/2001
First Model or Test Unit	2/12/2001	A-107984-G	40-45	1. Michael Simpson	2/14/2001
				2. Robin L. Graham	2/14/2001
First Test of Invention	2/12/2001	A-107984-G	40-45	1. Michael L. Simpson	2/14/2001
				2. Robin L. Graham	2/14/2001

List any other permanent records of the invention:

Please submit with this form copies of notebook entries and other records and reports relating to the invention. These documents may be essential in determining inventorship and date of the invention.

---

15. PUBLICATION STATUS: Has the invention been disclosed to the public or any party outside DOE and UT-Battelle?

☐YES ☒NO

If yes, provide the following information:

Was the disclosure cleared through the Technical Information Office? ☐YES (attach copy of clearance form) ☐NO

Indicate the form(s) of the disclosure: ☐Oral ☐Visuals ☐Abstract ☐Full Article ☐Other

☐Submitted for review, but not yet published

Date of Conference or Publication: Location of Conference: Journal:

Other relevant information

---

16. ROUTINE USE OF THE INVENTION:

If the inventors have tested any embodiment of the invention, has there been any additional, routine use of the invention?

☐YES ☒NO

If yes indicate date and circumstances of first such use:

PART III - MANAGEMENT REVIEW: (To be completed by submitter's supervisor, division management, or program manager)

17. Invention Achievement: This invention represents a
☐Pioneer Breakthrough ☒Major Improvement ☐Minor Improvement

18. Claims and Enforceability: (check all that apply)

The invention is a:	☒Method	☒Product	☒Machine	☐Composition of Matter
Is the invention detectable in a product?	☒Yes	☐Somewhat	☒No (can be practiced in secret)	
Scope of the invention is:	☒Broad	☐Intermediate	☐Narrow	
Discovery by another is likely in:	☐1 year	☒3 years	☐5 years	
"Inventing around" the invention would be:	☐Easy	☒Moderate	☐Difficult	

19. Quality of Description:
☐Description, documentation, data, drawings, etc. are complete.
☒Description is reasonably complete.
☐Further information is needed to support a patent application.

20. Potential Use of the Invention:
☐U.S. Government only ☒Manufacturer ☒Consumer
☒U.S.A. Companies: Forest Products Industry, Teaching and Research
Products: Wood, Paper, and Fiber Products
☒Foreign Countries: U.S., All Europe, Brazil, South Africa
Companies:

21. Market Value of the Invention:
Estimated total U.S. market: Present: $13M 5 years $700M
Estimated total world market: Present: $25M 5 years $1.25B
Use by others (1-10) + Near-term potential (1-10) + Value to related invention disclosures (1-10) = Total (≤30)

(+ +) = ☐

22. Recommended Disposition:
☒UT-Battelle should elect and file patent application. ☐Program or division will finance patent application.
☐DOE should file patent application. ☐Do not file a patent application.

23. Reviewer Comments:

Reviewer Name, printed or typed: Robin L. Graham Position: Section Head
Reviewer Signature: Robin Lambert Graham Date: 3-7-01

24. CLASSIFICATION: (To be completed by classification officer, or derivative classifier if not DUSA)
This document is properly classified as:
☐Confidential ☐Secret ☐Restricted Data ☐Formerly Restricted Data ☐National Security Information
☒Unclassified (Contains no classified information) ☐**DUSA (no signature required)**
Signature: David R Hamrin Date: 3/8/01

25. RECEIPT BY INTELLECTUAL PROPERTY SECTION: ***(This form must be complete in order to be accepted.)***
Received by: Shelley L. Spafford Date: 3-13-01

13. D. Full Name: Rupert Wimmer SS#: 410-73-4347 Citizenship: Austria

Current Employer: Institute of Botany, University of Agricultural Science Vienna

Work Address: Gregor Mendelstrasse 33, A-1180, Vienna, Austria

INVENTION DISCLOSURE
FROM
UT-BATTELLE, LLC

DOE CASE NO.: S- 96,692 **DISCLOSURE NO.: 0934**

SUBMITTED BY: Darrell C. West, Michael J. Paulus, Gerald A. Tuskan and Rupert Wimmer*

TITLE: Measurement of Wood/Plant Cell or Composite Material Attributes with Computer Assisted Tomography

BRIEF DESCRIPTION OF THE INVENTION: The subject invention disclosed herein is a method for measuring cell dimensions, such as cell length, cell diameter and cell wall thickness, of wood and plant cells or other composite material using computer assisted tomography. The existing ORNL rotating-state Micro CT imaging system has been modified and improved by modifying the x-ray tube focal spot size and the system geometry. The system and method of the subject invention are also used to obtain physical measures from reconstituted wood products such as oriented strand board, medium density fiber board and exuded wood products. The measured parameters relate to product quality and product performance. The method and system of the subject invention can be used in production settings to provide real-time quality information on wood and fiber-resin composite products. As such, it can be used in solid timber production facilities, reconstituted wood product facilities, and other fiber-resin production facilities.

Non-enabling title and abstract of the invention: same

DESCRIPTION OF THE INVENTION:
A description of the subject invention, related art, pertinent facts are set forth in the appended Report of Possible Subject Invention.
This invention is related to the following earlier disclosures:

1. ERID 0429 (S-88,699), patent application pending
2. ERID 0521 (S-90,811), patent application pending

POTENTIAL RIGHTS ISSUES:
There does not appear to be any third party involvement in the invention.
The invention does not appear to be subject to an "exceptional circumstance" as defined by the Prime Contract between UT-Battelle and the DOE.

*Visiting scientist on leave from Austrian Agricultural University; Not subject to 35 USC 212 nor 35 USC 202; assigned rights to ORNL

REMARKS:
It appears that: sufficient information is available to form the basis for a patent application; the invention appears to be distinct from known prior art; there is no potential U.S. statutory bar nor potential foreign bar.

Patent Agent: SLS

EXHIBIT
tabbies
"B"

OAK RIDGE NATIONAL LABORATC.<Y
MANAGED BY UT-BATTELLE, LLC
FOR THE U.S. DEPARTMENT OF ENERGY

REPORT OF POSSIBLE SUBJECT INVENTION

ORNL-40 *Electronically fillable in WORD 97 or newer* (04/01/2000)

Int ll..tual Property Secti n Use Only

Disclosure No. 0934

DOE S-96,692

INSTRUCTIONS: Place pointer over highlighted text to reveal instructions here and throughout this document.

PART I - DESCRIPTION OF THE INVENTION

1. SUBMITTER(s): (First/initial/last)

Darrell C. West, Michael J. Paulus, Gerald A. Tuskan, Rupert Wimmer

2. TITLE: (10 words maximum)

Measurement of Wood/Plant Cell or Composite Material Attributes with Computer Assisted Tomography

3. BRIEF DESCRIPTION OF THE INVENTION:

Computer Assisted Tomography (CT) scanning techniques allow direct measurements of wood cell-wall thickness, cell diameter, and cell-vacuole diameter. The system described here consists of a fixed X-ray source, an X-ray detector, and a rotating sample stage. The sample is subjected to a cone beam of X-rays which serves to magnify the image projected into an area detector. The digital image of X-ray attenuation can then be analyzed in either a two- or three-dimensional space. Since the degree of attenuation is a function of material density, quantification is possible for the solid material of the cell wall and the air space (vacuole) within each cell. The digit output and reconstructed images from this approach allows measurements of wood-cell attributes (see Fig. 1).

4. BACKGROUND: (Problem your invention solves)

In pine and hardwood tree species, which are frequently used for pulp, paper and forest products, plant cells form rapid cell walls surrounding an empty vacuole, which can vary in diameter from 10 to 50 um. Within an annual growth cycle, large-diameter, thin-walled cells are produced at the beginning of the growing season, while smaller-diameter, thicker-walled cells are produced near the end of the growing season, thus producing "annual rings." In addition to variation within a given year's growth, wood cell anatomy varies from year to year. The wood formed during the earlier years of growth and near the crown of a tree is called "juvenile" wood and typically has lower density and shorter, thinner-walled fibers than mature wood. Because final paper and/or lumber quality is determined by cell wall attributes, improving wood quality is an important endeavor.

Cell-length and cell-wall-thickness measurements are currently made with standard visual microscopic techniques. However, sample preparation during traditional cell-wall-thickness studies requires several meticulous laboratory steps, including softening and maceration of the wood and microscope slide preparation. Such preparations inadvertently affect the obtained measures. In addition to being cumbersome, cell-length data obtained by the traditional method contain errors because they include measurements of truncated cells produced by the preparation process. Furthermore, large sample-preparation and data-analysis time requirements limit the usefulness of the traditional cell-size-determination procedure in genetic selection studies in which hundreds of samples need to be processed as quickly as possible. The methodology proposed here eliminates the physical, chemical, and visual steps in the laboratory, thus accelerating and simplifying the data-acquisition process and cell attribute determinations.

5. DETAILED DESCRIPTION OF THE INVENTION: (How to make and use, method steps, best mode, drawings of all embodiments)

METHODOLOGY

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2. Reconstruct a 2-dimensional 1024 x 1024 pixel image slice. Each pixel in the image is 5.4 x 5.4 microns.

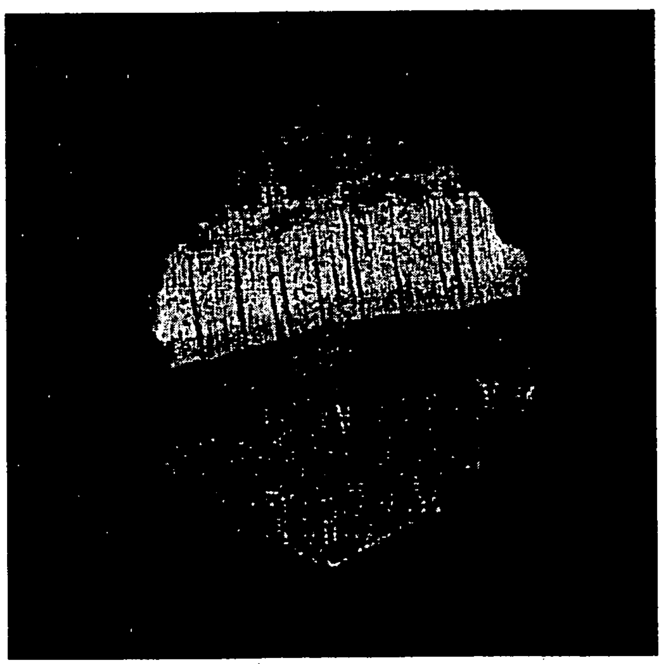

Figure 1. Representative micro CT reconstructed image.

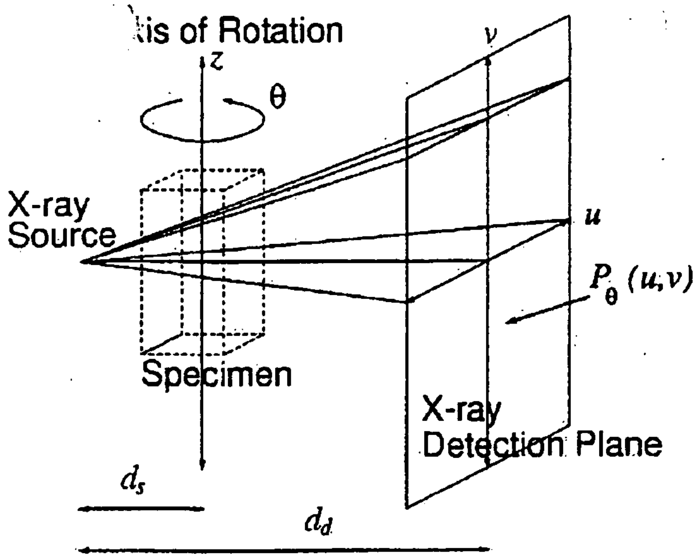

Figure 2. Conceptual representation of the generic configuration of x-ray source, focal spot, and system geometry as it affect spatial resolution.

3. Determine the number of cells per unit length for ~20 radial cell rows (Fig. 3). Determine mean cell size in this dimension.

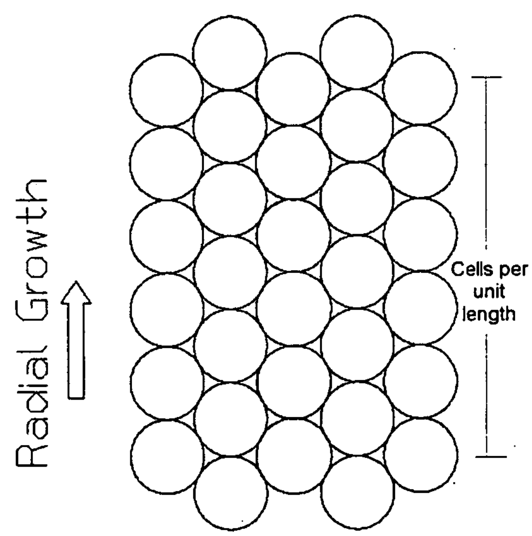

Figure 3. Radial orientation of cell size measurement.

4. Determine the number of tangential rows per unit length (Fig. 4). Determine mean cell size in this dimension.

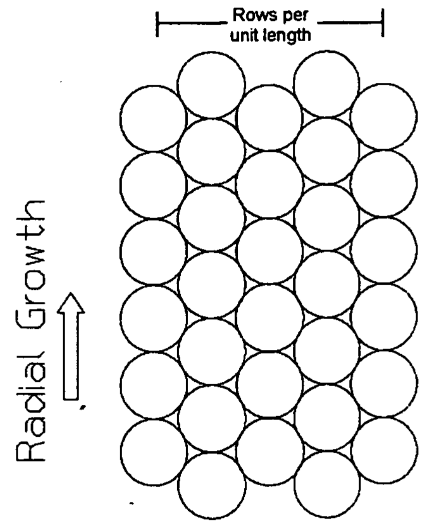

Figure 4. Tangential orientation of cell size measurement.

5. Model the cell as a hexagon with an effective size (flat-to-flat) equal to the average of the radial and tangential cell sizes and with a circular vacuole (Fig. 5).

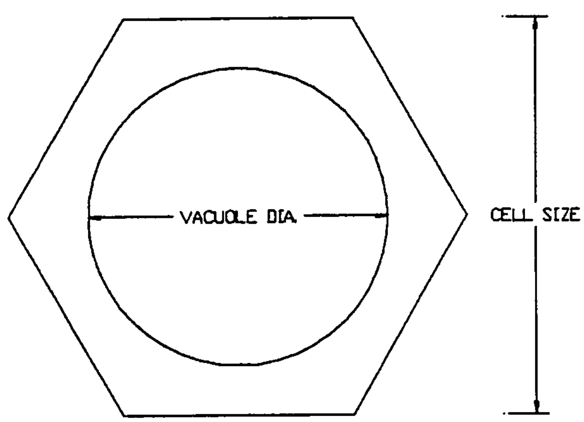

Figure 5. Assumed generic cell geometry.

6. Assume the average radio-density (D_{avg}) may be expressed as:

$$D_{avg} = (A_v D_v + A_c D_c)/(A_v + A_c),$$

Where, A_v is the average vacuole area, D_v is the known radio-density of air, A_c is the average per-cell area of the cellulose cell walls, and D_c is the known radio-density of cellulose. Solve for the fractional areas of the vacuoles and cellulose.

7. Given the known cell size (Step 4) and known fractional areas (Step 6) calculate the vacuole diameter.

8. Calculate the cell wall thickness as the difference between the cell size and the vacuole diameter.

APPARATUS

An apparatus is claimed that will automatically perform all or some of the following functions to analyze wood samples.

1. Trim a raw sample to a size that fits within the field of view of the x-ray computed tomography system or other three-dimensional imaging system.
2. Acquire 3-dimensional image data using x-ray CT or some other imaging method.
3. Determine the average cell size by measuring the mean period (in two dimensions) of the cellular structure.
4. Determine the average cell wall thickness by measuring the mean density of the sample, calculating the ratio of the cell wall material volume to the lumen material, and fitting the ratio to the measured cell size.
5. Automatically determine the average cell length by either
    a. searching the entire image volume for cell ends and determining the number of cell ends per unit volume.
    b. searching one or more 2D image slices for cell ends and extrapolating to estimate the number of cell ends per unit volume.

IMPROVEMENTS

The current resolution is limited by the geometric relationship between the size of the detector array and the size of the X-ray source. Our prototype produces a functional resolution of ca. 12 um. It is technically feasible to achieve a resolution near 1-2 um. At this resolution estimates of cell length are obtainable. In addition, computation time associated with image could be reduced through two modifications to the current prototype. First, the response time of the detector array could be enhanced, shortening the time required to capture the X-ray density data. Second, the computer operating platform could be shifted from a PC base to a UNIX platform on a workstation or to a parallel computer platform.

---

6. RELATED TECHNOLOGY: (List all relevant publications, patents, etc. of yours and others, and submit a copy of each with this form.)

o ORNL

Micro CT of small animals (see attached papers)
Micro CT for wood ring analysis, Applied Biotechnology and Biochemistry (see attached papers)

o Elsewhere

X-ray computed tomography is a mature field in the medical community and has also been used to analyze the micro structure of soil, biological and other samples.

7. UNIQUE FEATURES: (List all features that distinguish the invention over the technology listed in Item 6.)

This is the first time that X-ray CT scan has achieved the above configuration. This is also the first, as a result of the configuration, that direct, non-distributed measures of plant cell wall dimensions are obtainable.

8. POSSIBLE ALTERNATIVE VERSIONS:

Alternate applications:

1. Determine the uniformity of wood chip orientation in composite materials by performing 2D and 3D Fourier analysis of the image volume.
2. Determine the volumetrically varying orientation of wood chips by performing 2D and 3D Fourier analysis of the image volume.
3. Determine the volumetrically varying wood-to-resin ratio in composite materials by measuring the x-ray attenuation coefficients or other related parameter in composite material samples.
4. Evaluate the defect density in wood and composite material samples through image analysis of the x-ray CT or other image data set.
5. Determine the void density in wood or composite material samples through image analysis of the x-ray CT or other image data set.
6. Determine the volume of moisture uptake in wood or composite material samples through image analysis of the x-ray CT or other image data set.
7. Extend all claims to include any fiber-resin composite materials.

9. PROBABLE USES: (Anticipated U.S. Government, Industry, foreign uses of the invention)

We have already described the Micro CT scan's possible use in measuring plant cell attributes such as cell diameter, cell lumin diamtere, cell wall thickness and cell length. This same instrument could be used to obtain physical measures from reconstituted wood products such as oriented strand board, medium density fiber board and exuded wood products. Our preliminary data indicates that measures of fiber orientation, fiber dimensions and fiber to air space measures in these products are feasible. These measured parameters related to product quality and product performance. Instruments could be used in a wide array of research settings -- government and industry wood product laboratories and academic laboratories addressing woody plant structure and function. Furthermore, we could envision the invention being used in production settings to provide real-time quality information on wood and fiber-resin composite products. As such, it could be used in solid timber production facilities, reconstituted wood product facilities, and other fiber-resin production facilities.

PART II - FACTS RELATING TO THE INVENTION

10. REDUCTION TO PRACTICE : Select one of the following responses:

- ☐ Invention is purely conceptual and needs experimentation to validate the concept.
- ☐ Invention is conceptual, but does not need experimentation to validate the concept.
- ☐ Proof-of-principle experiment has been performed to validate the concept.
- ☒ Invention has been demonstrated on a [☐ laboratory; ☒ prototype; ☐ production] scale.
- ☐ Other (Explain):

11. SOURCE(S) OF FUNDS: (Funding under which the invention arose)

- ☐ DOE B&R Code:
- ☐ 100% funds-in from third party identified below
- ☐ LDRD
- ☒ Seed Money
- ☐ Other:

Identify respective Program Manager: Terry Sjoreen

12. THIRD PARTY: Is a third party involved in the invention? ☐ YES ☒ NO

If yes, provide the following information:

Note: A submitter who is not a UT-Battelle employee is a third party.

- ☐ CRADA
- ☐ Subcontract
- ☐ Interagency Agreement
- ☐ Work For Others
- ☐ No written agreement
- ☐ Other:

Name of third party:

Contract or Agreement No. Effective dates:

Explain any special circumstances:

13. SUBMITTERS: Each submitter must provide all the following information and original signature.

A. Full Name Darrell C. West SS#: 414-74-4623 Citizenship: USA

Residence Address: 2150 Phillips Road, Lenoir City, TN 37771 Telephone: 865-986-6470

Current Employer: ☐ *UT-Battelle* ☒ Other: Retired UT-Battelle

Employee No.: Work Address: Telephone: : - -

DIVISION No.: 42 Name: Environemtnal Sciences Manager: S. G. Hildebrand Supervisor: R. L.Graham

My specific contribution to the concept of the invention is: Project coordinator and initial conceptual development

Recorded in Notebook # Page(s) Date of Entry* Witnessed by:

Employer on *Date of Entry: ☐ *UT-Battelle* ☐ Other:

DIVISION No.: Name: Manager: Supervisor:

If Other, explain relationship to UT-Battelle and provide a copy of agreement, subcontract, or other documentation:

I have read and understood the contents of this document: Signature: NOT AVAILABLE FOR SIGNATURE Date: ________

B. Full Name Michael J. Paulus SS#: 410-13-7816 Citizenship: USA

Residence Address: 1516 Moorgate Drive, Knoxville, TN 37922 Telephone: 865- -

Current Employer: ☒ *UT-Battelle* ☐ Other:

Employee No.: 36220 Work Address: MS-6006 Telephone: : 865-241-4802

DIVISION No.: 9 Name: Instrumentation and Controls Manager: W. L. Bryan Supervisor: W.L. Bryan

My specific contribution to the concept of the invention is: Expertise in CT x-ray densitometry

Recorded in Notebook # A-107984-G Page(s) 40-45 Date of Entry* 2/12/2001 Witnessed by: M.L. Simpson and R.L Graham

Employer on *Date of Entry: ☒ *UT-Battelle* ☐ Other:

DIVISION No.: Name: Manager: Supervisor:

If Other, explain relationship to UT-Battelle and provide a copy of agreement, subcontract, or other documentation:

I have read and understood the contents of this document: Signature: NOT AVAILABLE FOR SIGNATURE Date: ________

C. Full Name Gerald A. Tuskan SS#: 526-23-6899 Citizenship: USA

Residence Address: 120 Newridge Road, Oak Ridge., TN Telephone: 865-481-8346

Current Employer: ☒ *UT-Battelle* ☐ Other:

Employee No.: 30576 Work Address: MS-6422 Telephone: : 865-576-8141

DIVISION No.: 42 Name: Environemntal Sciences Manager: S. G. Hildebrand Supervisor: R. Graham

My specific contribution to the concept of the invention is: Initial conceptual contributions and biological applications.

Recorded in Notebook # Page(s) Date of Entry* Witnessed by:

Employer on *Date of Entry: ☐ *UT-Battelle* ☐ Other:

DIVISION No.: Name: Manager: Supervisor:

If Other, explain relationship to UT-Battelle and provide a copy of agreement, subcontract, or other documentation:

I have read and understood the contents of this document: Signature: Gerald A. Tuskan Date: 3/8/01

D. Full Name Rupert Wimmer SS#: 410-73-4347 Citizenship: Austria

Residence Address: Telephone: - -

Current Employer: ☐ *UT-Battelle* ☒ Other: See Attached Sheet

Employee No.: Work Address: See Attached Sheet Telephone: : - -

DIVISION No.: 42 Name: Environmental Sciences Manager: S. G. Hildebrand Supervisor: S. B. McLaughlin

My specific contribution to the concept of the invention is: Fourier Analysis of density data for oriented strand board.

Recorded in Notebook # Page(s) Date of Entry* Witnessed by:

Employer on *Date of Entry: ☐ *UT-Battelle* ☐ Other:

DIVISION No.: Name: Manager: Supervisor:

If Other, explain relationship to UT-Battelle and provide a copy of agreement, subcontract, or other documentation:

I have read and understood the contents of this document: Signature: NOT AVAILABLE FOR SIGNATURE Date: ________

E Full Name SS#: - - Citizenship:

Residence Address: Telephone: - -

Current Employer: ☐ *UT-Battelle* ☐ Other:

Employee No.: Work Address: Telephone: : - -

DIVISION No.: *Name:* *Manager:* *Supervisor:*

My specific contribution to the concept of the invention is:

Recorded in Notebook # Page(s) Date of Entry* Witnessed by:

Employer on *Date of Entry: ☐ *UT-Battelle* ☐ Other:

DIVISION No.: *Name:* *Manager:* *Supervisor:*

If Other, explain relationship to UT-Battelle and provide a copy of agreement, subcontract, or other documentation:

I have read and understood the contents of this document: Signature: ______________________________ Date: _________

F. Full Name SS#: - - Citizenship:

Residence Address: Telephone: - -

Current Employer: ☐ *UT-Battelle* ☐ Other:

Employee No.: Work Address: Telephone: : - -

DIVISION No.: *Name:* *Manager:* *Supervisor:*

My specific contribution to the concept of the invention is:

Recorded in Notebook # Page(s) Date of Entry* Witnessed by:

Employer on *Date of Entry: ☐ *UT-Battelle* ☐ Other:

DIVISION No.: *Name:* *Manager:* *Supervisor:*

If Other, explain relationship to UT-Battelle and provide a copy of agreement, subcontract, or other documentation:

I have read and understood the contents of this document: Signature: ______________________________ Date: _________

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14. NOTEBOOK RECORDS : All items must be accurately completed. An inventor cannot be a witness.

EVENT	DATE	NOTEBOOK NO.	PAGES	TWO NOTEBOOK WITNESSES	WITNESS DATES
Original Concept	2/12/2001	A-107984-G	40-45	1. Michael L. Simpson	2/14/2001
				2. Robin L. Graham	2/14/2001
First Sketch or Drawing	2/12/2001	A-107984-G	40-45	1. Michael L. Simpson	2/14/2001
				2. Robin L. Graham	2/14/2001
First Written Description	2/12/2001	A-107984-G	40-45	1. Michael Simpson	2/14/2001
				2. Robin L. Graham	2/14/2001
First Model or Test Unit	2/12/2001	A-107984-G	40-45	1. Michael Simpson	2/14/2001
				2. Robin L. Graham	2/14/2001
First Test of Invention	2/12/2001	A-107984-G	40-45	1. Michael L. Simpson	2/14/2001
				2. Robin L. Graham	2/14/2001

List any other permanent records of the invention:

Please submit with this form copies of notebook entries and other records and reports relating to the invention. These documents may be essential in determining inventorship and date of the invention.

15. PUBLICATION STATUS: Has the invention been disclosed to the public or any party outside DOE and UT-Battelle?

☐YES ☒ NO

If yes, provide the following information:

Was the disclosure cleared through the Technical Information Office? ☐YES (attach copy of clearance form) ☐NO

Indicate the form(s) of the disclosure: ☐Oral ☐Visuals ☐Abstract ☐Full Article ☐Other

☐Submitted for review, but not yet published

Date of Conference or Publication: Location of Conference: Journal:

Other relevant information

16. ROUTINE USE OF THE INVENTION:

If the inventors have tested any embodiment of the invention, has there been any additional, routine use of the invention?

☐YES ☒NO

If yes indicate date and circumstances of first such use:

PART III - MANAGEMENT REVIEW: (To be completed by submitter's supervisor, division management, or program manager)

17. Invention Achievement: This invention represents a
☐ Pioneer Breakthrough ☒ Major Improvement ☐ Minor Improvement

18. Claims and Enforceability: (check all that apply)

The invention is a:	☒ Method	☒ Product	☒ Machine	☐ Composition of Matter
Is the invention detectable in a product?	☒ Yes	☐ Somewhat	☒ No (can be practiced in secret)	
Scope of the invention is:	☒ Broad	☐ Intermediate	☐ Narrow	
Discovery by another is likely in:	☐ 1 year	☒ 3 years	☐ 5 years	
"Inventing around" the invention would be:	☐ Easy	☒ Moderate	☐ Difficult	

19. Quality of Description:
☐ Description, documentation, data, drawings, etc. are complete.
☒ Description is reasonably complete.
☐ Further information is needed to support a patent application.

20. Potential Use of the Invention:
☐ U.S. Government only ☒ Manufacturer ☒ Consumer
☒ U.S.A. Companies: Forest Products Industry, Teaching and Research
Products: Wood, Paper, and Fiber Products
☒ Foreign Countries: U.S., All Europe, Brazil, South Africa
Companies:

21. Market Value of the Invention:
Estimated total U.S. market: Present: $13M 5 years $700M
Estimated total world market: Present: $25M 5 years $1.25B
Use by others (1-10) + Near-term potential (1-10) + Value to related invention disclosures (1-10) = Total (≤30)

(+ +) = ☐

22. Recommended Disposition:
☒ UT-Battelle should elect and file patent application.
☐ Program or division will finance patent application.
☐ DOE should file patent application.
☐ Do not file a patent application.

23. Reviewer Comments:

Reviewer Name, printed or typed: Robin L. Graham Position: Section Head

Reviewer Signature: Robin Lambert Graham Date: 3-7-01

24. CLASSIFICATION: (To be completed by classification officer, or derivative classifier if not DUSA)
This document is properly classified as:
☐ Confidential ☐ Secret ☐ Restricted Data ☐ Formerly Restricted Data ☐ National Security Information
☒ Unclassified (Contains no classified information) ☐ **DUSA (no signature required)**

Signature: David R Hamrin Date: 3/8/01

25. RECEIPT BY INTELLECTUAL PROPERTY SECTION: ***(This form must be complete in order to be accepted.)***

Received by: Shelley L. Spafford Date: 3-13-01

CONFIDENTIAL INFORMATION

This document contains patentable subject matter and is disclosed in confidence by UT-Battelle, LLC under 35 USC § 205.

13. D. Full Name: Rupert Wimmer SS#: 410-73-4347 Citizenship: Austria

Current Employer: Institute of Botany, University of Agricultural Science Vienna

Work Address: Gregor Mendelstrasse 33, A-1180, Vienna, Austria

Subject Micro CT for Wood Anatomy Studies

Date FEB 12 ~~19~~ 2001 Year

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE, LLC
FOR THE U.S. DEPARTMENT OF ENERGY

REPORT OF POSSIBLE SUBJECT INVENTION

ORNL-40 Electronically fillable in WORD 97 or newer (04/01/2000)

Intellectual Property Section Use Only
Disclosure No. ______
DOE S- ______

INSTRUCTIONS: Place pointer over highlighted text to reveal instructions here and throughout this document.[JM1]

PART I - DESCRIPTION OF THE INVENTION

1. SUBMITTER(s): [JM2] (First/initial/last)

Darrell C. West, Michael J. Paulus, Gerald A. Tuskan

2. TITLE: [JM3] (10 words maximum)

Measurement of Wood/Plant Cell Attributes with Computer Assisted Tomography

3. BRIEF DESCRIPTION OF THE INVENTION:[JM4]

Computer Assisted Tomography (CT) scanning techniques allow direct measurements of wood cell-wall thickness, cell diameter, and cell-vacuole diameter. The system described here consists of a fixed X-ray source, an X-ray detector, and a rotating sample stage. The sample is subjected to a cone beam of X-rays which serves to magnify the image projected into an area detector. The digital image of X-ray attenuation can then be analyzed in either a two- or three-dimensional space. Since the degree of a attenuation is a function of material density, quantification is possible for the solid material of the cell wall and the air space (vacuole) within each cell. The digit output and reconstructed images from this approach allows measurements of wood-cell attributes (see Fig. 1).

4. BACKGROUND: [JM5] (Problem your invention solves)

In pine and hardwood tree species, which are frequently used for pulp, paper and forest products, plant cells form rapid cell walls surrounding an empty vacuole which can vary in diameter from 10 to 50 um. Within an annual growth cycle, large-diameter, thin-walled cells are produced at the beginning of the growing season, while smaller-diameter, thicker-walled cells are produced near the end of the growing season, thus producing "annual rings." In addition to variation within a given year's growth, wood cell anatomy varies from year to year. The wood formed during the earlier years of growth and near the crown of a tree is called "juvenile" wood and typically has lower density and shorter, thinner-walled fibers than mature wood. Because final paper and/or lumber quality is determined by cell wall attributes, improving wood quality is an important endeavor.

Cell-length and cell-wall-thickness measurements are currently made with standard visual microscopic techniques. However, sample preparation during traditional cell-wall-thickness studies requires several meticulous laboratory steps, including softening and maceration of the wood and microscope slide preparation. Such preparations inadvertently affects the obtained measures. In addition to being cumbersome, cell-length data obtained by the traditional method contain errors because they include measurements of truncated cells produced by the preparation process. Furthermore, large sample-preparation and data-analysis time requirements limit the usefulness of the traditional cell-size-determination procedure in genetic selection studies in which hundreds of samples need to be processed as quickly as possible. The methodology proposed here eliminates the physical, chemical, and visual steps in the laboratory, thus accelerating and simplifying the data-acquisition process and cell attribute determinations.

5. DETAILED DESCRIPTION OF THE INVENTION:[JM6] (How to make and use, method steps, best mode, drawings of all embodiments)

The resolution and field of view of a X-ray CT system are determined primarily by the X-ray tube focal spot size, the spatial resolution of the X-ray source, and the system geometry. A generic representation of these parameters is presented in Figure 2. As previously configured, the ORNL imaging system was optimized for whole-body mouse scans with a reconstructed image resolution of approximately 100 microns full width, at half maximum (FWHM) and a minimum detectable feature size of about 50 microns.

Image resolution in radiographic systems is frequently defined in terms of the "modulation transfer function" (MTF), which is essentially the frequency (Fourier) domain representation of the spatial resolution. An advantage of MTF analysis is that multiple

Michael J Paulus Feb 12, 2001
Gerald A Tuskan 2/14/01
Robin L Graham 2/14/01

Continued on page 41

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Read and understood by Michael [signature] Badge 34325 Date 2-14-01

Subject Micro CT for Wood Anatomy Studies

Date FEB 12 2001 ~~19~~ Month Day Year

contributors to the overall spatial resolution may be analyzed independently; the overall resolution is then the frequency-domain product of the individual components.

Results from this reconfigured prototype indicated that a 12-micron resolution, through the use of an X-ray source with a smaller focal spot size and by adjustment of the geometry to ensure that the X-ray focal spot size is the dominant component of the MTF, is achievable. In this high-resolution configuration, the field of view has been reduced to approximately 2.5 mm, but the resolution and field of view is suited for direct measurement of wood cell diameter, cell-wall thickness, and vacuole width. The reconstructed image is approximately 12 um FWHM.

Because cell lumin diameter is greater than the image resolution, this cell dimension is measured directly from the image. Cell-wall thickness is considerably less than the image resolution, thus the average cell-wall thickness is determined by counting the number of cells per unit area, measuring the mean image density, and employing a priori knowledge of the radio-density of the cell wall.

The following is a step-wise progression of procedures used for measuring cell-wall diameter, cell-wall thickness, and vacuole diameter using X-ray Micro-CT:

1. MicroCT images are acquired using a rotating-state microCT system with resolution of ~10 microns. The system uses a 1024 x 1024 element detector with a field of view of 5.5 mm.

2. Reconstruct a 2-dimensional 1024 x 1024 pixel image slice. Each pixel in the image is 5.4 x 5.4 microns.

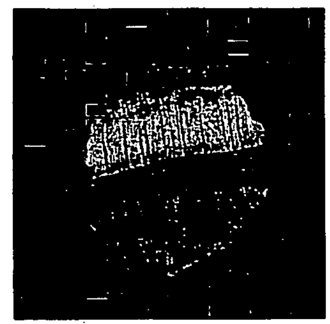

Figure 1. Representative micro CT reconstructed image.

Michael J Paulus Feb 12, 2001
Robin L Graham 2/14/01
Gerald A Tuskan 2/14/01

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EXHIBIT "C"

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Subject Micro CT For Wood Anatomy Studies

Date FEB 12, 2001 Month Day ~~19~~ Year

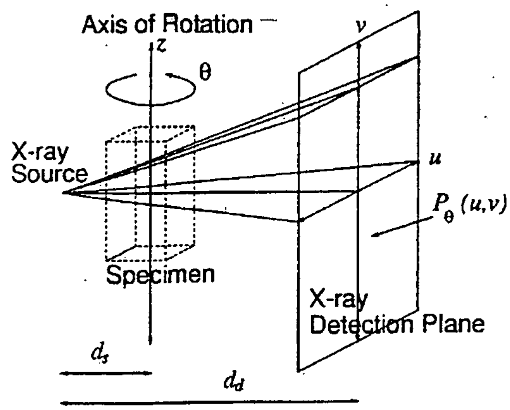

Figure 2. Conceptual representation of the generic configuration of x-ray source, focal spot, and system geometry as it affect spatial resolution.

3. Determine the number of cells per unit length for ~20 radial cell rows (Fig. 3). Determine mean cell size in this dimension.

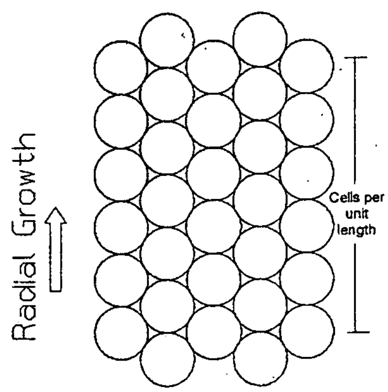

Figure 3. Radial orientation of cell size measurement.

[signature] FEB 12, 2001

[signature] 2-14-01

[signature] 2/14/01

CONFIDENTIAL INFORMATION

This document contains patentable subject matter and is disclosed in confidence by UT-Battelle, LLC under 35 USC § 205.

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Continued on page 43

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[signature] 2-14-07
Read and understood by Date
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Subject Microct for Wood Anatomy Studies

Date FEB 12, 2001 Month Day Year

4. Determine the number of tangential rows per unit length (Fig. 4). Determine mean cell size in this dimension.

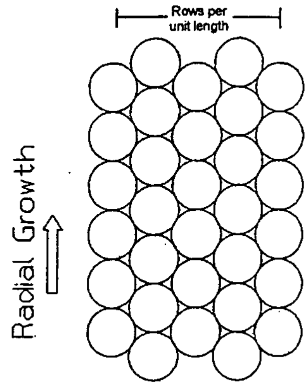

Figure 4. Tangential orientation of cell size measurement.

5. Model the cell as a hexagon with an effective size (flat-to-flat) equal to the average of the radial and tangential cell sizes and with a circular vacuole (Fig. 5).

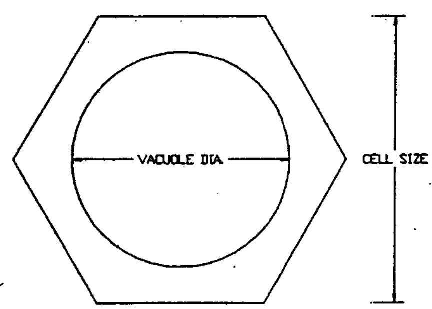

Figure 5. Assumed generic cell geometry.

Michael J Paulus
FEB 12, 2001
Robin L Graham 2/14/01
Donald L. Todd
2/14/01

UCN-6201

Continued on page 44

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Read and understood by Date 2/14/01

Badge 34385

Subject MicroCT for Wood Anatomy Studies

Date Feb 12, 2001 ~~19~~
Month Day Year

6. Assume the average radio-density (D_{avg}) may be expressed as:

$$D_{avg} = (A_v D_v + A_c D_c)/(A_v + A_c),$$

Where, A_v is the average vacuole area, D_v is the known radio-density of air, A_c is the average per-cell area of the cellulose cell walls, and D_c is the known radio-density of cellulose. Solve for the fractional areas of the vacuoles and cellulose.

7. Given the known cell size (Step 4) and known fractional areas (Step 6) calculate the vacuole diameter.

8. Calculate the cell wall thickness as the difference between the cell size and the vacuole diameter.

6. RELATED TECHNOLOGY:[JM7] (List all relevant publications, patents, etc. of yours and others, and submit a copy of each with this form

Mike you will have to complete this section.

7. UNIQUE FEATURES: [JM8] (List all features that distinguish the invention over the technology listed in Item 6.)

This is the first time that X-ray CT scan has achieved the above configuration. This is also the first, as a result of the configuration, that direct, non-distributed measures of plant cell wall dimensions are obtainable.

8. POSSIBLE ALTERNATIVE VERSIONS:[JM9]

The current resolution is limited by the geometric relationship between the size of the detector array and the size of the X-ray source. Our prototype produces a functional resolution of ca. 12 um. It is technically feasible to achieve a resolution near 1-2 um. At this resolution estimates of cell length are obtainable. In addition, computation time associated with image could be reduced through two modifications to the current prototype. First, the response time of the detector array could be enhanced, shortening the time required to capture the X-ray density data. Second, the computer operating platform could be shifted from a PC base to a UNIX platform on a workstation or to a parallel computer platform. This would require some codes to be re-written.

9. PROBABLE USES: [JM10] (Anticipated U.S. Government, Industry, foreign uses of the invention)

We have already described the Micro-CT scans possible use in measuring plant cell attributes such as cell diameter, cell lumin diamtere, cell wall thickness and cell length. This same instrument could be used to obtain physical measures from reconstituted wood products such as oriented strand board, medium density fiber board and exuded wood products. Our preliminary data indicates that measures of fiber orientation, fiber dimensions and fiber to air space measures in these products are feasible. These measured parameters related to product quality and product performance.

Feb 12, 2001

Robert Graham 2/14/01

2/14/01

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This document contains patentable subject matter and is disclosed in confidence by UT-Battelle, LLC under 35 USC § 205.

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Continued on page 45

Recorded by Date

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Date

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Subject MicroCT for Wood Anatomy Studies

Date Feb 12, 2001 ~~19~~
Month Day Year

Apparatus

An apparatus is claimed that will automatically perform all or some of the following functions to analyze wood samples.

1. Trim a raw sample to a size that fits within the field of view of the x-ray computed tomography system or other three-dimensional imaging system.

2. Acquire 3-dimensional image data using x-ray CT or some other imaging method.

3. Determine the average cell size by measuring the mean period (in two dimensions) of the cellular structure.

4. Determine the average cell wall thickness by measuring the mean density of the sample, calculating the ratio of the cell wall material volume to the lumen material, and fitting the ratio to the measured cell size.

5. Automatically determine the average cell length by either

   a. searching the entire image volume for cell ends and determining the number of cell ends per unit volume.

   b. searching one or more 2D image slices for cell ends and extrapolating to estimate the number of cell ends per unit volume.

Alternate applications:

1. Determine the uniformity of wood chip orientation in composite materials by performing 2D and 3D Fourier analysis of the image volume.

2. Determine the volumetrically varying orientation of wood chips by performing 2D and 3D Fourier analysis of the image volume.

3. Determine the volumetrically varying wood-to-resin ratio in composite materials by measuring the x-ray attenuation coefficients or other related parameter in composite material samples.

4. Evaluate the defect density in wood and composite material samples through image analysis of the x-ray CT or other image data set.

5. Determine the void density in wood or composite material samples through image analysis of the x-ray CT or other image data set.

6. Determine the volume of moisture uptake in wood or composite material samples through image analysis of the x-ray CT or other image data set.

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